T-VER-P-METH-14-02

CO_2 Capture for Utilization for Concrete Production

Version 01

Scope: 05 – Chemical industry

Scope: 06 – Construction

Entry into force on 24 September 2025

Thailand Greenhouse Gas Management Organization (Public Organization) (TGO)

1. Methodology	CO_2 Capture and Utilization for Concrete Production
2. Project Type	Capture, storage, and/or utilization of greenhouse gas
3. Scope	Scope: 05 – Chemical industry Scope: 06 – Construction
4. Project Outline	The project activity must aim to capture carbon dioxide (CO_2) either from a defined point source or through Direct Air Capture (DAC) to be utilized in concrete production process.
5. Applicability	The project activity must include a process for capturing gas from the emission source and separating CO_2 (Capture), as well as utilizing the CO_2 (Utilization) in concrete production for permanent CO_2 storage. The proportion of cement used in the concrete product must not increase compared to the baseline scenario
6. Project Conditions	1) The concrete produced from the project activity must have a compressive strength equivalent to that of conventional concrete (baseline scenario) and must comply with engineering standards applicable to its intended use, as well as with the Thai Industrial Standard TIS 213-2520. 2) The concrete produced from the project activity must be utilized in commercial applications. 3) The project activity may include processes for CO_2 liquefaction, CO_2 evaporation, and the transportation of CO_2 via vehicles or pipelines. 4) The project activity may involve the use of additives in cement or concrete. 5) The project activity must not involve concrete recycling. 6) The utilization of CO_2 under the concrete production project activity requires project developers to specify a permanent serial number on the concrete to enable traceability. 7) The project developer must monitor and verify the total amount of CO_2 captured through the capture process, as well as the amount of CO_2 utilized in concrete production, to ensure accuracy and completeness.

7. Project Starting Date	The date on which the project owner (employer) and the contractor jointly signed the construction or installation agreement for the greenhouse gas reduction project to be developed as a T-VER project.
8. Definition	**Concrete** refers to a mixture of cement, sand, gravel, and water commonly used in various types of construction work, such as fresh concrete, concrete for road construction, structural concrete, and concrete for bridge building. **Cement** refers to a binding material used in concrete production, primarily composed of limestone, clay, silica, alumina, and gypsum. During the cement manufacturing process, carbon dioxide is released through a chemical reaction known as calcination. **Calcination** refers to the process of converting limestone ($CaCO_3$), whose primary component is calcium carbonate, into calcium oxide (CaO), during which carbon dioxide (CO_2) is released as a result of a chemical reaction. **Carbonation plant** refers to the facility or site where concrete mixing processes are carried out to enable carbonation during project implementation. **Independent Power Supply (IPS)** refers to a private power producer that generates electricity for self-consumption without supplying it to the grid or selling it directly to end-users. **Direct Mineral Carbonation** refers to A chemical reaction occurs between CO_2 and metal oxides (alkali or alkaline earth metals), such as calcium oxide (CaO) and magnesium oxide (MgO) which are components of cement and water, resulting in the formation of calcium carbonate ($CaCO_3$) or magnesium carbonate ($MgCO_3$). These compounds are chemically stable minerals capable of permanently storing CO_2. **Indirect Mineral Carbonation** refers to the carbon sequestration process of CO_2 during concrete production involves two key reactions: first, the interaction between CO_2, silica oxide (SiO_2) in cement, and water; followed by the extraction of calcium from

	calcium silicate hydrate compounds and a direct carbonation reaction that leads to the crystallization of calcium carbonate ($CaCO_3$), enabling permanent CO_2 storage.
9. Note	

Details of T-VER Methodology for

CO_2 Capture and Utilization for Concrete Production

1. Emission reductions activities used in the calculations

Table 1: Sources and Types of Greenhouse Gases

Greenhouse gas emission	Source	Greenhouse Gas	Details of activities that emit greenhouse gas emissions
Baseline Emission	A defined industrial stack emission	CO_2	▪ Fossil fuel combustion ▪ Calcination of limestone
	Carbon dioxide in the atmosphere	CO_2	Anthropogenic and natural activities
	Baseline concrete	CO_2	Mass of carbon contained in baseline concrete
	Baseline emission from cement	CO_2	Emission from cement production process
Project Emission	Concrete used in project activity	CO_2	Mass of carbon in concrete during project implementation
	Cement used in project activity	CO_2	Emission from cement production process
	Carbon capture and separation		
	▪ Leakage	CO_2	Machinery/Equipment/Pipeline system
	▪ On-site electricity and heat generation for process use	CO_2	Combustion of fossil fuels in power plants within the project boundary
	▪ Use of externally purchased electricity and thermal energy in the process	CO_2	▪ Electricity generation by grid-connected power plants ▪ Electricity and/or steam generation by IPS-type power plants
	Preparation of CO_2 in liquid form		

	▪ On-site electricity generation for process use	CO_2	Combustion of fossil fuels in power plants within the project boundary
	▪ Electricity consumption (purchased from external sources) in the process	CO_2	▪ Electricity generation by grid-connected power plants ▪ Electricity and/or steam generation by IPS-type power plants
	CO_2 transportation		
	▪ Release or leakage	CO_2	Machinery/Equipment/Pipeline system
	▪ Use of fossil fuels	CO_2	Fuel combustion from transportation vehicles
	▪ Electricity consumption (purchased from external sources) in the process	CO_2	▪ Electricity generation by grid-connected power plants ▪ Electricity and/or steam generation by IPS-type power plants
	Preparation of CO_2 in vapor phase		
	▪ Use of fossil fuels	CO_2	Fossil fuel combustion within the project boundary
	▪ On-site electricity generation for process use	CO_2	Fossil fuel combustion in power plants within the project boundary
	▪ Electricity consumption (purchased from external sources) in the process	CO_2	▪ Electricity generation by grid-connected power plants ▪ Electricity and/or steam generation by IPS-type power plants
	Utilization of CO_2 in concrete production		
	▪ Release or leakage	CO_2	Machinery/Equipment/Pipeline system
	▪ Use of fossil fuels	CO_2	Fossil fuel combustion within the project boundary

	▪ On-site electricity generation for use in the process	CO_2	Combustion of fossil fuels in power plants within the project boundary
	▪ Electricity consumption (purchased from external sources) in the process	CO_2	▪ Electricity generation by grid-connected power plants ▪ Electricity generation by IPS-type power plants
	Use of solvents in the CO_2 utilization process	CO_2	Solvent production process
Leakage Emission	<u>Transportation of gravel, sand, water, and cement</u>		
	▪ Use of fossil fuels	CO_2	Fuel combustion from vehicles used for transportation
	▪ Electricity consumption (purchased from external sources) in the process	CO_2	▪ Electricity generation by grid-connected power plants ▪ Electricity generation by IPS-type power plants

2. Scope of Project

The project activity must aim to capture carbon dioxide either from a point-source emission or directly from the atmosphere, and store within concrete products.

- Carbon storage in concrete must ensure that the performance characteristics of the resulting concrete, when used in various applications, are equivalent to those of baseline concrete or meet the relevant standards for that specific type of concrete.
- The transportation of cement, aggregates (gravel and sand), and water from outside the project boundary refers to the transport of materials used for the production of concrete that exceeds the baseline production volume.

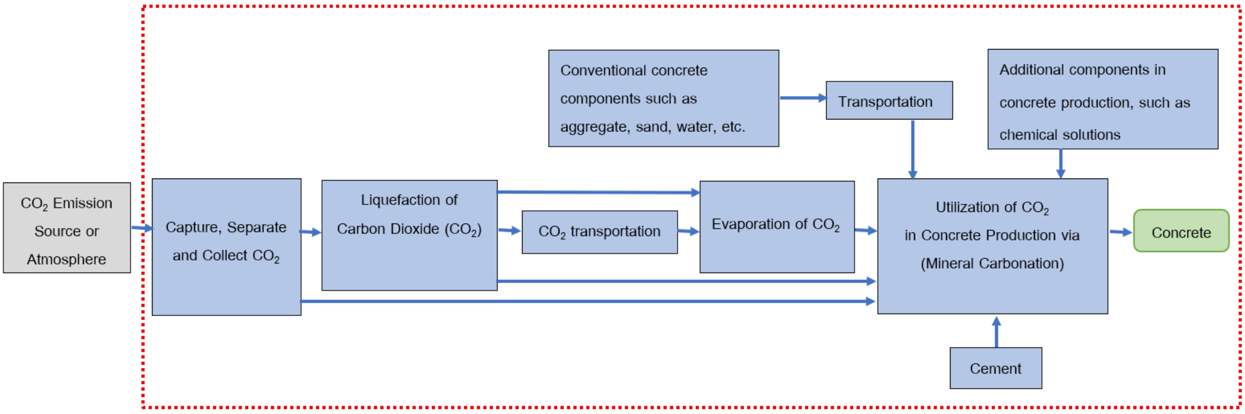

Figure 1: Carbon Dioxide Capture and Storage Process in Concrete Production

The project activity consists of five distinct components, as illustrated in Figure 1

- **CO_2 capture and separation** from point sources can be carried out at various stages, as outlined below
  - Pre-combustion
  - Post-combustion
  - Oxy-fuel combustion
  - Direct Air Capture

  Examples of Technologies Used for CO_2 Capture
  - Adsorption
  - Absorption
  - Membrane separation
  - Cryogenic distillation
  - Chemical Looping
- **CO_2 Preparation (Liquefaction):** Converting CO_2 into its liquid state to optimize transportation efficiency
- **Transportation** The separated CO_2 can be transported to the designated area for utilization in concrete production through various modes of transportation, including
  - Pipeline
  - Land transportation

In cases where the CO_2 capture and separation process (Capture) and the CO_2 collection (Collection) occur at the same location as the carbonation plant, allowing direct CO_2 feed into concrete production, greenhouse gas emissions from transportation activities shall not be considered or shall be deemed zero.

- **CO_2 Evaporation:** Converting CO_2 into its gaseous state to optimize its suitability as a feedstock for mineral carbonation in the carbonation plant
- **Utilization of CO_2** within the carbonation plant occurs through the mineral carbonation process to produce various types of concrete, such as fresh concrete, pavement concrete, structural concrete (architectural concrete), and bridge concrete. This process constitutes the storage of CO_2 within the concrete, whereby CO_2 is chemically transformed into calcium carbonate ($CaCO_3$), becoming an integral part of the concrete matrix.

$$Ca(OH)_2 + CO_2 \leftrightharpoons CaCO_3 + H_2O$$

The project activity may not include CO_2 liquefaction, CO_2 transportation, or CO_2 evaporation processes as illustrated in Figure 1, depending on the actual implementation of the project.

3. Additionality

The project must undergo further proof of operation from normal operations. (Additionality) using the “Proof of Operations Guidelines in addition to normal operations (Additionality) under the Thailand Voluntary Emission Reduction Program (T-VER)" standard equivalent to the international standards prescribed by the TGO.

4. Baseline Scenario

The project activity involving carbon dioxide capture for utilization in concrete production represents the first of its kind in Thailand. Therefore, the baseline information refers to the amount of CO_2 that is utilized and subsequently stored within the concrete during the production process

Note: If Thailand sees an increase in CCU projects for concrete production, TGO (Thailand Greenhouse Gas Management Organization) will consider revising the baseline data in accordance with the 'Below Business as Usual (Below BAU) approach

If the utilization of CO_2 in concrete production results in a reduction in cement consumption, Below Business as Usual (Below BAU) baseline approach may be applied. In such cases, the baseline concrete production shall be considered to use hydraulic cement with a greenhouse gas emission factor of 871 $kgCO_2$ per ton of cement.

5. Baseline Emission

Baseline emission is considered only from carbon dioxide (CO_2) from a specific designated source. The calculation is based on the amount of carbon in concrete that increases under conventional operations, combined with the use of cement, which releases CO_2 during its production process.

Baseline emission can be calculated as followed:

$$BE_y = \sum_n (BE_{CO2,Store,n,y}) + BE_{Cement,y} \qquad \text{Equation (1)}$$

Where

BE_y	=	Baseline emissions in year y (tCO_2e/year)
$BE_{CO2,Store,n,y}$	=	Quantity of carbon dioxide calculated based on the difference between the amount of carbon stored in concrete type n under project implementation and that in the baseline case in year y (tCO_2/year)
$BE_{Cement,y}$	=	Baseline emissions from concrete production based on the amount of hydraulic cement used in year y (tCO_2/year)

5.1 Quantity of carbon dioxide calculated based on the difference between the amount of carbon stored in concrete under project implementation and that in the baseline case ($BE_{CO2,Store,n,y}$)

Quantity of carbon dioxide calculated based on the difference between the amount of carbon stored in concrete under project implementation and that in the baseline case may be calculated using one of the following three approaches.

<u>Option 1:</u> Direct Measurement of Carbon Content in Baseline Concrete

The amount of carbon dioxide sequestered in baseline concrete may be calculated based on the measured carbon content in concrete samples combined with total concrete production data. The calculation may be performed using the following equation.

$$BE_{CO2,Store,n,y} = \sum_i \left[Q_{Concrete,PJ,i,y} \times ((Q_{C,PJ,Test,i} - Q_{C,BL,Test,i}) \times 10^6 \times \frac{44}{12})\right] \qquad \text{Equation (2)}$$

Where

$BE_{CO2,Store,i,y}$	=	Quantity of carbon dioxide calculated based on the difference between the amount of carbon stored in concrete type i under project implementation and that in the baseline case in year y (tCO_2/year)
$Q_{Concrete,PJ,i,y}$	=	Quantity of concrete type i produced by the project activity in year y (t concrete/year)
$Q_{C,PJ,Test,i,y}$	=	Average carbon (C) content in samples of concrete type i from the project activity in year y (gram of C/gram of tested concrete)
$Q_{C,BL,Test,i}$	=	Average carbon (C) content in samples of concrete type i from the baseline case (gram of C/gram of tested concrete)
i	=	Type of concrete

Option 2: Assessment via Measured Volume of CO_2 Supplied to the Carbonation Plant

The amount of carbon dioxide sequestered in baseline concrete may be calculated based on the measured volume of CO_2 gas entering the carbonation plant and the residual volume of CO_2 remaining within the system. The residual CO_2 may be considered as project emissions in cases where the carbonation process operates under a closed system. Alternatively, it may be excluded from the calculation if the CO_2 is sourced from ambient air or would otherwise have been released under normal conditions. The assessment shall be conducted per concrete production batch, with energy consumption during the process maintained at a constant level.

The amount of carbon dioxide sequestered in baseline concrete may be calculated as followed. The carbonation process must operate under a closed system, with no leakage of gas during the reaction phase.

$$BE_{CO2,Store,i,y} = \sum_b (Q_{CO2,PJ,Feed,i,b,y} - Q_{CO2,PJ,Non\text{-}Store,i,b,y}) \qquad \text{Equation (3)}$$

Where

$BE_{CO2,Store,i,y}$	=	Quantity of carbon dioxide calculated based on the difference between the amount of carbon stored in concrete type i under project implementation and that in the baseline case in year y (tCO_2/year)

$Q_{CO2,PJ,Feed,i,b,y}$ = Amount of CO_2 used for injection into the carbonation plant for producing concrete type i in production batch b under the project activity in year y (tCO_2/year)

$Q_{CO2,PJ,Non\text{-}Store,i,b,y}$ = Amount of residual CO_2 remaining in the carbonation plant (not stored in concrete) for concrete type i in production batch b under the project activity in year y (tCO_2/year)

i = Type of concrete

b = Concrete production batch

The amount of CO_2 gas injected into the carbonation plant per concrete production cycle (b) may be calculated based on the gas density, the proportion of CO_2 in the gas mixture, and the total volume of gas supplied to the carbonation plant. The calculation may be performed using the following equation.

$$Q_{CO2,PJ,Feed,i,b,y} = \sum_{t,b}\left[\rho_{CO2,b} \times (\%V/V_{CO2,Feed,i,b,y}) \times V_{Feed,b} \times 10^{3}\right] \quad \text{Equation (4)}$$

Where

$Q_{CO2,PJ,Feed,i,b,y}$ = Amount of CO_2 used for injection into the carbonation plant for producing concrete type i in production batch b under the project activity in year y (tCO_2/year)

$\rho_{CO2,b}$ = Density of CO_2 under operating conditions in concrete production batch b (kg/m^3)

$\%V/V_{CO2,Feed,i,b,y}$ = Volumetric proportion of CO_2 to total gas volume at the injection point of the carbonation plant, measured during concrete production batch b under operational conditions in year y (%)

$V_{Feed,b}$ = Volume of CO_2 injected into the carbonation plant during concrete production batch b (m^3)

i = Type of concrete

b = Concrete production batch

The amount of CO_2 gas not sequestered as carbonate in concrete may be calculated based on the free volume, pressure, and temperature within the reaction chamber, combined with the CO_2 concentration and gas density. This assessment shall be conducted per concrete production cycle (b), using the following equation.

$$Q_{CO2,PJ,Non\text{-}Store,i,b,y} = \sum_b \left(\frac{P_{After,b}\, V_{Chamber,b}}{R\ T_{After,b}} - \frac{P_{Before,b}\, V_{Chamber,b}}{R\ T_{Before,b}} \right) \times (\%V/V_{CO2,Feed,i,b,y}) \times 44.01 \times 10^{-6}$$

Equation (5)

Where

$Q_{CO2,PJ,Non\text{-}Store,i,b,y}$	=	Amount of residual CO_2 remaining in the carbonation plant (not stored in concrete) for concrete type i in production batch b under the project activity in year y (tCO_2/year)
$P_{After,b}$	=	Pressure within the chamber after the completion of the concrete production batch b (bar), following the mineral carbonation reaction inside the chamber
$P_{Before,b}$	=	Pressure within the chamber prior to operation during concrete production batch b (bar), before CO_2 is fed into the chamber
$V_{Chamber,b}$	=	Void volume within the chamber during concrete production batch b (m^3)
R	=	Gas constant = 8.314472×10^{-5} (m^3 bar K^{-1} mol^{-1})
$T_{After,b}$	=	Temperature within the chamber after operation during concrete production batch b (K), following completion of the mineral carbonation reaction in the chamber
$T_{Before,b}$	=	Temperature within the chamber prior to operation during concrete production batch b (K), before CO_2 is injected into the chamber
$\%V/V_{CO2,Feed,i,b,y}$	=	Volumetric ratio of CO_2 to total gas volume at the injection point of the carbonation plant, measured during concrete production batch b under operational conditions in year y (%)
i	=	Type of concrete
b	=	Concrete production batch

<u>Option 3: Assessment Using System Efficiency Estimates</u>

The amount of carbon dioxide sequestered in baseline concrete may be calculated using an estimated system efficiency value of 0.6, based on a conservative approach of experimental results published by Monkman, S. (2018)

In this case, the amount of carbon dioxide sequestered in baseline concrete may be calculated using the following equation.

$$BE_{CO2,Store,n,y} = \Sigma_b \left(Q_{CO2,PJ,Feed,i,b,y} \times 0.6\right) \quad \text{Equation (6)}$$

Where

$BE_{CO2,Store,i,y}$	=	Quantity of carbon dioxide calculated based on the difference between the amount of carbon stored in concrete type i under project implementation and that in the baseline case in year y (tCO_2/year)
$Q_{CO2,PJ,Feed,i,b,y}$	=	Amount of CO_2 used for injection into the carbonation plant for producing concrete type i in production batch b under the project activity in year y (tCO_2/year)
0.6	=	Amount of carbon dioxide transformed into mineral forms in concrete based on the conservative calculation approach, as referenced from the principle of conservative estimation for mineralization potential during concrete production referred from the academic publication by Monkman, S. (2018)[6].
n	=	Type of concrete
b	=	Concrete production batch

5.2 Baseline emissions from concrete production based on the amount of hydraulic cement used (BE_{Cement})

Baseline emissions from concrete production based on the amount of hydraulic cement used can be calculated as followed:

$$BE_{Cement,y} = \Sigma_i Q_{Cement,BL,i,y} \times EF_{HC} \quad \text{Equation (7)}$$

Where

$BE_{Cement,y}$	=	Baseline emissions from concrete production based on the amount of hydraulic cement used in year y (tCO_2/year)
$Q_{Cement,BL,i,y}$	=	Quantity of hydraulic cement used in the production of concrete type i from the baseline case in year y (t cement)
EF_{HC}	=	Emission factor from hydraulic cement production (tCO_2/t cement)
i	=	Type of concrete

5.2.1 Quantity of hydraulic cement used in the production of concrete from the baseline case ($Q_{Cement,BL,i,y}$)

Quantity of hydraulic cement used in the production of concrete from the baseline case shall be assessed by comparing the quantity of hydraulic cement contained in baseline concrete sample type i with that in the corresponding project concrete sample

The amount of cement used in baseline concrete production may be calculated as followed:

$$Q_{Cement,BL,i,y} = \sum_i \left(Q_{Cement,PJ,i,y} \times \left(\frac{Q_{Cement,BL,Test,i}}{Q_{Cement,PJ,Test,i}}\right)\right) \qquad \text{Equation (8)}$$

Where

$Q_{Cement,BL,i,y}$	=	Quantity of hydraulic cement used in the production of concrete type i from the baseline case in year y (t cement)
$Q_{Cement,PJ,i,y}$	=	The quantity of cement used in the production of concrete type i in year y (t cement)
$Q_{Cement,BL,Test,i}$	=	Quantity of hydraulic cement utilized in the preparation of concrete type i samples under the baseline scenario (gram of cement)
$Q_{Cement,PJ,Test,i}$	=	Quantity of hydraulic cement utilized in the preparation of concrete type i samples under the project activity (gram of cement)
i	=	Type of concrete

6. Project Emission

Project emission from the project activity is considered based on seven key components of the project operations, namely: Cement consumption during project implementation CO_2 capture process CO_2 separation and collection process CO_2 transportation process CO_2 liquefaction process CO_2 evaporation process and Mineral carbonation process. Additionally, the acquisition of solvents used to accelerate the mineral carbonation reaction is also considered. Only components that are implemented within the project scope shall be considered.

Project emission can be calculated as followed:

$$PE_y = PE_{Cement,y} + PE_{Capt,y} + PE_{Liq,y} + PE_{Trans,y} + PE_{Evap,y} + PE_{MineralC,y} + PE_{Solvent,y} \qquad \text{Equation (9)}$$

Where

PE_y = Project emissions in year y (tCO_2e/year)

$PE_{Cement,y}$ = Project emissions from concrete production based on the amount of hydraulic cement used in year y (tCO_2/year)

$PE_{Capt,y}$ = Project emissions from CO_2 capture, separation, and collection processes in year y (tCO_2/year)

$PE_{Liq,y}$ = Project emissions from liquefying CO_2 in year y (tCO_2/year)

$PE_{Trans,y}$ = Project emissions from the CO_2 transportation process in year y (tCO_2/year)

$PE_{Evap,y}$ = Project emissions from the vaporization of CO_2 in year y (tCO_2/year)

$PE_{MineralC,y}$ = Project emissions from conditioning the chamber (carbonation plant) to achieve suitable temperature and pressure for mineral carbonation in year y (tCO_2/year)

$PE_{Solvent,y}$ = Project emissions from the use of concrete admixture in year y (tCO_2/year)

6.1 Project emissions from concrete production based on the amount of hydraulic cement used ($PE_{Cement,y}$)

Project emissions from concrete production based on the amount of hydraulic cement used can be calculated as followed:

$$PE_{Cement,y} = \sum_i (Q_{Cement,PJ,j,y} \times EF_{Cement,j}) \qquad \text{Equation (10)}$$

Where

$PE_{Cement,y}$ = Project emissions from concrete production based on the amount of hydraulic cement used in year y (tCO_2/year)

$Q_{Cement,PJ,j,y}$ = Quantity of cement type j used for concrete production under the project activity in year y (t cement)

$EF_{Cement,j}$ = Emission factor of cement type j under the project activity (tCO_2/t cement)

i = Type of concrete

6.2 Project emissions from CO2 capture, separation, and collection processes ($PE_{Capt,y}$)

Project emissions from CO_2 capture, separation, and collection processes can be calculated as followed:

$$PE_{Capt,y} = PE_{Capt,FF,y} + PE_{Capt,Elec,y} + PE_{Capt,IPS,y} \qquad \text{Equation (11)}$$

Where

$PE_{Capt,y}$	=	Project emissions from CO_2 capture, separation, and collection processes in year y (tCO_2/year)
$PE_{Capt,FF,y}$	=	Project emissions from fossil fuel combustion during the capture, separation, and collection of CO_2 in year y (tCO_2/year)
$PE_{Capt,Elec,y}$	=	Project emissions from electricity consumption from the grid during the capture, separation of CO_2 from other gases, and collection processes in year y (tCO_2/year)
$PE_{Capt,IPS,y}$	=	Project emissions from the use of electricity and/or steam supplied by IPS-type power plants for the CO_2 capture, separation from other gases, and collection processes in year y (tCO_2e/year)

6.2.1 Project emissions from fossil fuel combustion during the capture, separation, and collection of CO_2 ($PE_{Capt,FF,y}$)

Project emissions from fossil fuel combustion during the capture, separation, and collection of CO_2 such as heat generation for the regeneration of absorbents or adsorbents, and electricity and heat generation for CO_2 capture, separation, and collection (excluding externally purchased energy) shall be calculated using the latest version of the calculation tool T-VER-P-TOOL-02-01: Tool to Calculate Project or Leakage CO_2 Emissions from Fossil Fuel Combustion

6.2.2 Project emissions from electricity consumption from the grid during the capture, separation of CO_2 from other gases, and collection processes ($PE_{Capt,Elec,y}$)

Project emissions from electricity consumption from the grid during the capture, separation of CO_2 from other gases, and collection processes can be calculated based on the amount of electricity consumed, the emission factor associated with electricity generation/use, and the proportion of transmission and distribution losses in the grid, as expressed in the following equation.

$$PE_{Capt,Elec,y} = EC_{Capt,PJ,y} \times EF_{Elec,y} \times (1 + TDL_y) \times 10^{-3} \qquad \text{Equation (12)}$$

Where

$PE_{Capt,Elec,y}$	=	Project emissions from electricity consumption from the grid during the capture, separation of CO_2 from other gases, and collection processes in year y (tCO_2e/year)

$EC_{Capt,PJ,y}$ = Electricity consumption for the capture, separation of CO_2 from other gases, and collection processes in year y (kWh/year)

$EF_{Elec,y}$ = Emission factor for electricity generation/consumption in year y (tCO_2/MWh)

TDL_y = Average technical transmission and distribution losses for providing electricity in year y (%)

6.2.3 Project emissions from the use of electricity and/or steam supplied by IPS-type power plants for the CO_2 capture, separation from other gases, and collection processes ($PE_{Capt,IPS,y}$)

Project emissions from the use of electricity and/or steam supplied by IPS-type power plants for the CO_2 capture, separation from other gases, and collection processes shall be assessed based on fossil fuel combustion using an allocation approach. The resulting energy-related emissions shall then be calculated using the latest version of the calculation tool T-VER-P-TOOL-02-01: Tool to Calculate Project or Leakage CO_2 Emissions from Fossil Fuel Combustion.

$$FC_{Capt,IPS,y} = \left(1/\eta_{IPS,y}\right) \times TFC_{IPS,y} \times \left[\frac{\left(HC_{Capt,PJ,y} + \left(3.6 \times EC_{Capt,PJ,y}\right)\right)}{\left(HG_{IPS,y} + \left(3.6 \times EG_{IPS,y}\right)\right)}\right] \qquad \text{Equation (13)}$$

Where

$FC_{Capt,IPS,y}$ = Fossil fuel consumption for purchased electricity and/or heat generation used in the CO_2 capture, separation from other gases, and collection processes in year y (Unit/year)

$TFC_{IPS,y}$ = Total fossil fuel consumption by the power plant(s) supplying electricity and/or steam for use in year y (Unit/year)

$HC_{Capt,PJ,y}$ = Heat consumption for the CO_2 capture, separation from other gases, and collection processes in year y (MJ/year)

$HG_{IPS,y}$ = Total heat output generated by power plant(s) supplying electricity and/or steam used in year y (MJ/year)

$EG_{IPS,y}$ = Total electricity output generated by power plant(s) supplying electricity and/or steam used in year y (kWh/year)

$\eta_{IPS,y}$ = Average annual efficiency of the power plant in year y (value between 0 and 1)

6.3 Project emissions from liquefying CO_2 ($PE_{Liq,y}$)

Project emissions from liquefying CO_2 can be calculated as followed:

$$PE_{Liq,y} = PE_{Liq,Elec,y} + PE_{Liq,IPS,y} \quad \text{Equation (14)}$$

Where

$PE_{Liq,y}$	=	Project emissions from liquefying CO_2 in year y (tCO_2/year)
$PE_{Liq,Elec,y}$	=	Project emissions from grid electricity consumption during the liquefaction process of CO_2 in year y (tCO_2/year)
$PE_{Liq,IPS,y}$	=	Project emissions from the use of electricity and/or steam from IPS-type power plants for CO_2 liquefaction processes in year y (tCO_2/year)

6.3.1 Project emissions from grid electricity consumption during the liquefaction process of CO_2 ($PE_{Liq,Elec,y}$)

Project emissions from grid electricity consumption during the liquefaction process of CO_2 can be calculated based on the amount of electricity consumed, the emission factor associated with electricity generation/use, and the proportion of transmission and distribution losses in the grid, as expressed in the following equation.

$$PE_{Liq,Elec,y} = EC_{Liq,PJ,y} \times EF_{Elec,y} \times (1 + TDL_y) \times 10^{-3} \quad \text{Equation (15)}$$

Where

$PE_{Liq,Elec,y}$	=	Project emissions from grid electricity consumption during the liquefaction process of CO_2 in year y (tCO_2e/year)
$EC_{Liq,PJ,y}$	=	Electricity consumption for the CO_2 liquefaction process in year y (kWh/year)
$EF_{Elec,y}$	=	Emission factor for electricity generation/consumption in year y (tCO_2/MWh)
TDL_y	=	Average technical transmission and distribution losses for providing electricity in year y (%)

6.3.2 Project emissions from the use of electricity and/or steam from IPS-type power plants for CO_2 liquefaction processes ($PE_{Liq,IPS,y}$)

Project emissions from the use of electricity and/or steam from IPS-type power plants for CO_2 liquefaction processes shall be assessed based on fossil fuel combustion using an allocation approach. The resulting emissions shall then be calculated using the latest version of the calculation tool T-VER-P-TOOL-02-01: Tool to Calculate Project or Leakage CO_2 Emissions from Fossil Fuel Combustion.

$$FC_{Liq,IPS,y} = (1/\eta_{IPS,y}) \times TFC_{IPS,y} \times \left[\frac{(3.6 \times EC_{Liq,PJ,y})}{(HG_{IPS,y} + (3.6 \times EG_{IPS,y}))}\right] \quad \text{Equation (16)}$$

Where

$FC_{Liq,IPS,y}$ = Fossil fuel consumption for electricity generation associated with purchased electricity used in the CO_2 liquefaction process in year y (Unit/year)

$TFC_{IPS,y}$ = Total fossil fuel consumption by the power plant(s) supplying electricity and/or steam for use in year y (Unit/year)

$HG_{IPS,y}$ = Total heat output generated by power plant(s) supplying electricity and/or steam used in year y (MJ/year)

$EG_{IPS,y}$ = Total electricity output generated by power plant(s) supplying electricity and/or steam used in year y (kWh/year)

$\eta_{IPS,y}$ = Average annual efficiency of the power plant in year y (value between 0 and 1)

6.4 Project emissions from the CO_2 transportation process ($PE_{Trans,y}$)

Project emissions from the transportation of CO_2 captured, separated, and collected from other gases to the utilization site for mineral carbonation in concrete under the project activity can be calculated as followed:

$$PE_{Trans,y} = PE_{Trans,FF,y} + PE_{Trans,Elec,y} + PE_{Trans,IPS,y} \quad \text{Equation (17)}$$

Where

$PE_{Trans,y}$ = Project emissions from the CO_2 transportation process in year y (t CO_2/year), whereby if the location of CO_2 capture, separation and collection activities and the carbonation plant are within the same area, $PE_{Trans,y} = 0$

$PE_{Trans,FF,y}$ = Project emissions from the combustion of fossil fuels in machinery, equipment, or vehicles used for CO_2 transportation in year *y* (tCO_2/year)

$PE_{Trans,Elec,y}$ = Project emissions from grid electricity consumption for CO_2 transportation via pipeline in year y (tCO_2/year)

$PE_{Trans,IPS,y}$ = Project emissions from electricity and/or steam consumption supplied by an IPS-type power plant for CO_2 pipeline transportation in year y (tCO_2/year)

6.4.1 Project emissions from the combustion of fossil fuels in machinery, equipment, or vehicles used for CO_2 transportation ($PE_{Trans,FF,y}$)

Project emissions from fossil fuel combustion in vehicles used for transporting CO_2 captured, separated, and collected from other gases to the utilization site for mineral carbonation in concrete under the project activity shall be calculated using the latest version of the calculation tool T-VER-P-TOOL-02-01: Tool to Calculate Project or Leakage CO_2 Emissions from Fossil Fuel Combustion

6.4.2 Project emissions from electricity and/or steam consumption supplied by an IPS-type power plant for CO_2 pipeline transportation ($PE_{Trans,Elec,y}$)

Project emissions from electricity and/or steam consumption supplied by an IPS-type power plant for CO_2 pipeline transportation can be calculated as followed:

$$PE_{Trans,Elec,y} = EC_{Trans,PJ,y} \times EF_{Elec,y} \times (1 + TDL_y) \times 10^{-3} \quad \text{Equation (18)}$$

Where

$PE_{Trans,Elec,y}$	=	Project emissions from grid electricity consumption for CO_2 transportation via pipeline under project operations in year y (tCO_2e/year)
$EC_{Trans,PJ,y}$	=	Electricity consumption for CO_2 transportation under project operations in year y (kWh/year)
$EF_{Elec,y}$	=	Emission factor for electricity generation/consumption in year y (tCO_2/MWh)
TDL_y	=	Average technical transmission and distribution losses for providing electricity in year y (%)

6.4.3. Project emissions from electricity and/or steam consumption supplied by an IPS-type power plant for CO_2 pipeline transportation ($PE_{Trans,IPS,y}$)

Project emissions from electricity and/or steam consumption supplied by an IPS-type power plant for CO_2 pipeline transportation shall be assessed based on fossil fuel combustion using an allocation approach. The resulting emissions shall then be calculated using the latest version of the calculation tool T-VER-P-TOOL-02-01: Tool to Calculate Project or Leakage CO_2 Emissions from Fossil Fuel Combustion.

$$FC_{Trans,IPS,y} = \left(1/\eta_{IPS,y}\right) \times TFC_{IPS,y} \times \left[\frac{(3.6 \times EC_{Trans,PJ,y})}{(HG_{IPS,y} + 3.6 \times EG_{IPS,y})}\right] \quad \text{Equation (19)}$$

Where

$FC_{Trans,IPS,y}$	=	Fossil fuel consumption for electricity generation associated with purchased electricity used in the CO_2 transportation process in year y (Unit/year)
$TFC_{IPS,y}$	=	Total fossil fuel consumption by the power plant(s) supplying electricity and/or steam for use in year y (Unit/year)
$HG_{IPS,y}$	=	Total heat output generated by power plant(s) supplying electricity and/or steam used in year y (MJ/year)
$EG_{IPS,y}$	=	Total electricity output generated by power plant(s) supplying electricity and/or steam used in year *y* (kWh/year)
$\eta_{IPS,y}$	=	Average annual efficiency of the power plant in year y (value between 0 and 1)

6.5 Project emissions from the vaporization of CO_2 ($PE_{Evap,y}$)

Project emissions from the vaporization of CO_2 can be calculated as followed:

$$PE_{Evap,y} = PE_{Evap,Elec,y} + PE_{Evap,IPS,y} \quad \text{Equation (20)}$$

Where

$PE_{Evap,y}$	=	Project emissions from the vaporization of CO_2 in year y (tCO_2e/year)
$PE_{Evap,Elec,y}$	=	Project emissions from grid electricity consumption in the CO_2 vapor-phase preparation process in year y (tCO_2e/year)
$PE_{Evap,IPS,y}$	=	Project emissions from the use of electricity and/or steam supplied by IPS-type power plants for CO_2 vapor-phase preparation processes in year y (tCO_2e/year)

6.5.1 Project emissions from grid electricity consumption in the CO_2 vapor-phase preparation process ($PE_{Evap,Elec,y}$)

Project emissions from grid electricity consumption in the CO_2 vapor-phase preparation process can be calculated based on the amount of electricity consumed, the emission factor associated with electricity generation/use, and the proportion of transmission and distribution losses in the grid, as expressed in the following equation.

$$PE_{Evap,Elec,y} = EC_{Evap,PJ,y} \times EF_{Elec,y} \times (1 + TDL_y) \times 10^{-3} \quad \text{Equation (21)}$$

Where

$EC_{Evap,PJ,y}$	=	Electricity consumption for the preparation of CO_2 in vapor phase under project operations in year y (kWh/year)
$EF_{Elec,y}$	=	Emission factor for electricity generation/consumption in year y (tCO_2/MWh)
TDL_y	=	Average technical transmission and distribution losses for providing electricity in year y (%)

6.5.2 Project emissions from the use of electricity and/or steam supplied by IPS-type power plants for CO_2 vapor-phase preparation processes ($PE_{Evap,IPS,y}$)

Project emissions from the use of electricity and/or steam supplied by IPS-type power plants for CO2 vapor-phase preparation processes shall be assessed based on fossil fuel combustion using an allocation approach. The resulting emissions shall then be calculated using the latest version of the calculation tool T-VER-P-TOOL-02-01: Tool to Calculate Project or Leakage CO_2 Emissions from Fossil Fuel Combustion.

$$FC_{EV,IPS,y} = (1/\eta_{IPS,y}) \times TFC_{IPS,y} \times \left[\frac{(HC_{Evap,PJ,y} + (3.6 \times EC_{Evap,PJ,y}))}{(HG_{IPS,y} + (3.6 \times EG_{IPS,y}))}\right] \quad \text{Equation (22)}$$

Where

$FC_{Evap,IPS,y}$	=	Fossil fuel consumption for electricity and/or heat generation associated with purchased energy used in the CO_2 vapor-phase preparation process under project operations in year y (Unit/year)
$TFC_{IPS,y}$	=	Total fossil fuel consumption by the power plant(s) supplying electricity and/or steam for use in year y (Unit/year)
$HC_{Evap,PJ,y}$	=	Heat consumption for the preparation of CO_2 in vapor phase in year y (MJ/year)
$HG_{IPS,y}$	=	Total heat output generated by power plant(s) supplying electricity and/or steam used in year y (MJ/year)
$EG_{IPS,y}$	=	Total electricity output generated by power plant(s) supplying electricity and/or steam used in year *y* (kWh/year)
$\eta_{IPS,y}$	=	Average annual efficiency of the power plant in year y (value between 0 and 1)

6.6 Project emissions from conditioning the chamber (carbonation plant) to achieve suitable temperature and pressure for mineral carbonation ($PE_{MineralC,y}$)

Project emissions from conditioning the chamber (carbonation plant) to achieve suitable temperature and pressure for mineral carbonation can be calculated as followed:

$$PE_{MineralC,y} = PE_{MineralC,Elec,y} + PE_{MineralC,IPS,y} \quad \text{Equation (23)}$$

Where

$PE_{MineralC,y}$ = Project emissions from conditioning the chamber (carbonation plant) to achieve suitable temperature and pressure for mineral carbonation in year y (tCO_2e/year)

$PE_{MineralC,Elec,y}$ = Project emissions from electricity consumption from the power grid in the mineral carbonation production process in year y (tCO_2e/year)

$PE_{MineralC,IPS,y}$ = Project emissions from the use of electricity and/or steam supplied by an IPS-type power plant in the mineral carbonation production process in year y (tCO_2e/year)

6.6.1 Project emissions from electricity consumption from the power grid in the mineral carbonation production process ($PE_{MineralC,Elec,y}$)

Project emissions from electricity consumption from the power grid in the mineral carbonation production process can be calculated based on the amount of electricity consumed, the emission factor associated with electricity generation/use, and the proportion of transmission and distribution losses in the grid, as expressed in the following equation.

$$PE_{MineralC,Elec,y} = EC_{MineralC,PJ,y} \times EF_{Elec,y} \times (1 + TDL_y) \times 10^{-3} \quad \text{Equation (24)}$$

Where

$PE_{MineralC,Elec,y}$ = Project emissions from electricity consumption from the power grid in the mineral carbonation production process in year y (tCO_2e/year)

$EC_{MineralC,PJ,y}$ = Electricity consumption in the mineral carbonation production process in year y (kWh/year)

$EF_{Elec,y}$ = Emission factor for electricity generation/consumption in year y (tCO_2/MWh)

TDL_y = Average technical transmission and distribution losses for providing electricity in year y (%)

6.6.2 Project emissions from the use of electricity and/or steam supplied by an IPS-type power plant in the mineral carbonation production process ($PE_{MineralC,IPS,y}$)

Project emissions from the use of electricity and/or steam supplied by an IPS-type power plant in the mineral carbonation production process shall be assessed based on fossil fuel combustion using an allocation approach. The resulting emissions shall then be calculated using the latest version of the calculation tool T-VER-P-TOOL-02-01: Tool to Calculate Project or Leakage CO_2 Emissions from Fossil Fuel Combustion.

$$FC_{MineralC,IPS,y} = (1/\eta_{IPS,y}) \times TFC_{IPS,y} \times \left[\frac{(3.6 \times EC_{MineralC,PJ,y})}{(HG_{IPS,y} + (3.6 \times EG_{IPS,y}))}\right] \qquad \text{Equation (25)}$$

Where

$FC_{MineralC,IPS,y}$	=	Fossil fuel consumption for electricity generation in the purchased portion used in the mineral carbonation production process in year y (Unit/year)
$TFC_{IPS,y}$	=	Total fossil fuel consumption by the power plant(s) supplying electricity and/or steam for use in year y (Unit/year)
$HG_{IPS,y}$	=	Total heat output generated by power plant(s) supplying electricity and/or steam used in year y (MJ/year)
$EG_{IPS,y}$	=	Total electricity output generated by power plant(s) supplying electricity and/or steam used in year y (kWh/year)
$\eta_{IPS,y}$	=	Average annual efficiency of the power plant in year y (value between 0 and 1)

6.7 Project emissions from the use of concrete admixture ($PE_{Solvent,y}$)

Project emissions from the use of concrete admixture can be calculated as followed:

$$PE_{Solvent,y} = \Sigma_s(Q_{C,Solvent,PJ,s,y} \times \frac{44}{12}) + \Sigma_s((FC_{Solvent,s,y} \times EF_{Solvent,s,y}) \qquad \text{Equation (26)}$$

Where

$PE_{Sovent,y}$	=	Project emissions from the use of concrete admixture in year y (tCO_2e/year)
$Q_{C,Solvent,PJ,s,y}$	=	Carbon (C) content in solution type s for concrete mixing in year y (ton of C)
$FC_{Solvent,s,y}$	=	Consumption of solvent type s in year y (ton of solvent/year)

$EF_{Solvent,s,y}$	=	Emission factor of solvent type s (tCO_2e/ton of Solvent)
s	=	Type of solvent

6.7.1 Carbon (C) content in solution type s for concrete mixing ($Q_{C,Solvent,PJ,s,y}$)

Carbon (C) content in solution type s for concrete mixing can be calculated as followed:

$$Q_{C,Solvent,PJ,s,y} = Q_{Solvent,PJ,s,y} \times \frac{\text{Molar mass of C in solvent}_s}{\text{Total molar mass of solvent}_s}) \times \rho_{Solvent,S} \quad \text{Equation (27)}$$

Where

$Q_{C,Solvent,PJ,s,y}$	=	Carbon (C) content in solution type s for concrete mixing in year y (ton of C)
$Q_{Solvent,PJ,s,y}$	=	Volume of solution type s for concrete mixing from project implementation in year y (m^3)
Molar mass of C in solvent$_s$	=	Mass of carbon in 1 mole (mol) of solution type s (grams)
Total molar mass of solvent$_s$	=	Mass of 1 mole of solution type s (grams)
$\rho_{Solvent,S}$	=	Density of solution type s (kg/Liter, kg/dm^3)

6.7.2 Emission factor of solvent ($EF_{SOLVENT,s,y}$)

The emission factor for solvent types may be referenced from the following data sources.

Option 1: Emission Factor Based on Chemical Properties

- In cases where the chemical is not listed in available databases, the emission factor may be determined using a conservative approach. This involves applying the highest emission factor among chemicals within the same group, based on data from the Carbon Footprint of Products (CFP) published by the Thailand Greenhouse Gas Management Organization (TGO).
- In cases where the chemical is not listed within the same chemical group, the emission factor may be referenced using the calculation method outlined in the Carbon Footprint of Products (CFP) assessment guidelines established by the Thailand Greenhouse Gas Management Organization (TGO).

Option 2: Emission Factor from Online Databases suchas https://carboncloud.com/

Option 3: The emission factor may be obtained from calculation software tools such as SimaPro

7. Leakage Emission

Leakage emission shall be considered from the transportation of concrete mix materials used in the additional concrete production beyond the baseline scenario. These emissions may be calculated as followed:

$$LE_y = LE_{Trans,OB,FF,y} + LE_{Trans,OB,Elec,y} + LE_{Trans,OB,IPS,y} \quad \text{Equation (28)}$$

Where

LE_y	=	Leakage emission in year *y* (tCO_2e/year)
$LE_{Trans,OB,FF,y}$	=	Leakage emission from fossil fuel consumption for transporting concrete mix materials used in the production of concrete exceeding the baseline production level in year y (tCO_2e/year)
$LE_{Trans,OB,Elec,y}$	=	Leakage emission from the use of electricity from the power grid for transporting concrete mix materials used in additional concrete production beyond the baseline level in year y (tCO_2e/year)
$LE_{Trans,OB,IPS,y}$	=	Leakage emission from electricity consumption supplied by IPS-type power plants for the transportation of concrete mix materials used in the production of concrete beyond the baseline level in year y (tCO_2e/year)

7.1 Leakage emission from fossil fuel consumption for transporting concrete mix materials used in the production of concrete exceeding the baseline production ($LE_{Trans,OB,FF,y}$)

Leakage emission from fossil fuel consumption for transporting concrete mix materials used in the production of concrete exceeding the baseline production shall be calculated using the latest version of the TGO calculation tool: T-VER-P-TOOL-02-01: Tool to Calculate Project or Leakage CO_2 Emissions from Fossil Fuel Combustion.

7.2 Leakage emission from the use of electricity from the power grid for transporting concrete mix materials used in additional concrete production beyond the baseline level ($LE_{Trans,OB,Elec,y}$)

Leakage emission from the use of electricity from the power grid for transporting concrete mix materials used in additional concrete production beyond the baseline level shall be calculated based on the amount of electricity consumed, the grid emission factor, and the transmission and distribution loss rate, as shown in the following equation

$$LE_{Trans,OB,Elec,y} = EC_{Trans,OB,PJ,y} \times EF_{Elec,y} \times (1 + TDL_y) \times 10^{-3} \quad \text{Equation (29)}$$

Where

$EC_{Trans,OB,PJ,y}$	=	Electricity consumption for transporting concrete mix materials used in the production of concrete exceeding the baseline level in year y (tCO_2e/year)
$EF_{Elec,y}$	=	Emission factor for electricity generation/consumption in year y (tCO_2/MWh)
TDL_y	=	Average technical transmission and distribution losses for providing electricity in year y (%)

7.3 Leakage emission from electricity consumption supplied by IPS-type power plants for the transportation of concrete mix materials used in the production of concrete beyond the baseline level ($LE_{Trans,OB,IPS,y}$)

Leakage emission from electricity consumption supplied by IPS-type power plants for the transportation of concrete mix materials used in the production of concrete beyond the baseline level shall be assessed based on fossil fuel combustion. The allocation principle shall be applied to determine the proportion of fuel use attributable to the project activity. The resulting fuel consumption shall then be used to calculate greenhouse gas emissions using the latest version of the TGO calculation tool: T-VER-P-TOOL-02-01: Tool to Calculate Project or Leakage CO_2 Emissions from Fossil Fuel Combustion.

$$FC_{Trans,OB,IPS,y} = (1/\eta_{IPS,y}) \times TFC_{IPS,y} \times \left[\frac{(3.6 \times EC_{trans,OB,PJ,y})}{(HG_{IPS,y} + (3.6 \times EG_{IPS,y}))}\right] \quad \text{Equation (30)}$$

Where

$FC_{Trans,OB,IPS,y}$	=	Fossil fuel consumption for electricity generation in the purchased portion used for transporting concrete mix materials associated with

increased concrete production beyond the baseline level in year y (tCO_2e/year)

$TFC_{IPS,y}$ = Total fossil fuel consumption by the power plant(s) supplying electricity and/or steam for use in year y (Unit/year)

$HG_{IPS,y}$ = Total heat output generated by power plant(s) supplying electricity and/or steam used in year y (MJ/year)

$EG_{IPS,y}$ = Total electricity output generated by power plant(s) supplying electricity and/or steam used in year *y* (kWh/year)

$\eta_{IPS,y}$ = Average annual efficiency of the power plant in year y (value between 0 and 1)

8. Emission Reduction

Emission reduction can be calculated as followed:

$$ER_y = BE_y - PE_y - LE_y \quad \text{Equation (31)}$$

Where

ER_y = Emission reductions in year y (tCO_2e/year)

BE_y = Baseline emissions in year *y* (tCO_2e/year)

PE_y = Project emissions in year *y* (tCO_2e/year)

LE_y = Leakage emission in year *y* (tCO_2e/year)

9. Monitoring Plan

9.1 Monitoring approach

1) The project developer explains and specify the steps for monitoring the project activity data (Activity data) or verify all measurement results in the project proposal document. including the type of measuring instruments used Person responsible for monitoring results and verifying information Calibration of measuring instruments (if any) and procedures for warranty and quality control Where methods have different options, such as using default values or on-site measurements The project developer must specify which option to use. In addition, the installation, maintenance and calibration of measuring instruments should be carried out in accordance with the instructions of the equipment manufacturer and in accordance with national standards. or international standards such as IEC, ISO.

2) All data collected as part of the greenhouse gas reduction monitoring. The data should be stored in electronic file format and the retention period is in accordance with the guidelines set by the Administrative Organization or the organization's quality system, but the period of time is not less than that specified by the TGO. Must follow the follow-up methods specified in the follow-up parameters specified in Table 9.2.

9.2 Data and parameters monitored

Parameter	$Q_{Concrete,PJ,i,y}$
Unit	t concrete/year
Description	Quantity of concrete type i produced by the project activity in year y
Source of data	Record of the amount of concrete used from concrete manufacturers
Measurement procedures	Weighing of concrete load
Monitoring frequency	Continuous monitoring and at least monthly recording

Parameter	$Q_{Cement,PJ,j,y}$
Unit	t concrete/year
Description	Quantity of cement type j used for concrete production under the project activity in year y
Source of data	Record of the amount of concrete used from concrete manufacturers
Measurement procedures	Weighing of concrete load
Monitoring frequency	Continuous monitoring and at least monthly recording

Parameter	$Q_{C,PJ,Test,i,y}$
Unit	gram of C/gram of project tested concrete
Description	Average carbon (C) content in samples of concrete type i from the project activity in year y
Source of data	The results of the carbon content analysis in type I concrete samples under baseline conditions, conducted using reliable scientific instruments or analytical techniques
Measurement procedures	Carbon content analysis in type i concrete samples conducted during project implementation, using reliable scientific instruments or analytical techniques
Monitoring frequency	Continuous monitoring and at least monthly recording

Parameter	$\rho_{CO2,b}$
Unit	kg/m^3
Description	Density of CO_2 under operating conditions in concrete production batch b

Source of data	Table showing the density of CO_2 under various operational conditions.
Measurement procedures	Use the values from the table that correspond to the operational conditions of CO_2 used in delivery to the carbonation plant
Monitoring frequency	Each time concrete type n is produced in concrete production batch b

Parameter	$\%V/V_{CO2,Feed,i,b,y}$
Unit	-
Description	Volumetric proportion of CO_2 to total gas volume at the injection point of the carbonation plant, measured during concrete production batch b under operational conditions in year y
Source of data	Project data record
Measurement procedures	Continuous volumetric analysis, in conjunction with pressure and temperature measurements of the gas, is conducted to calculate the composition under standard conditions. The use of Gas Chromatography must be approved by the relevant authorities
Monitoring frequency	Continuous monitoring and at least monthly recording are required for the production of type n concrete during production cycle b

Parameter	$V_{Feed,b}$
Unit	m^3
Description	Volume of CO_2 injected into the carbonation plant during concrete production batch b
Source of data	Project data record
Measurement procedures	Continuous gas volume measurement, together with pressure and temperature monitoring, shall be conducted to calculate the volume under standard conditions. The flow meter used must be approved by the relevant authority
Monitoring frequency	Continuous monitoring and recording, at minimum on a monthly basis, are required for the production of type n concrete during production cycle b

Parameter	$V_{Chamber,b}$
Unit	m^3
Description	Void volume within the chamber during concrete production batch b
Source of data	Project data record
Measurement procedures	Measurements from the project
Monitoring frequency	Continuous monitoring and at least monthly recording

Parameter	$P_{After,b}$ and $P_{before,b}$
Unit	bar

Description	$P_{After,b}$ refer to internal pressure within the chamber after the completion of the concrete production batch b (bar), following the mineral carbonation reaction inside the chamber $P_{before,b}$ refer to internal pressure within the chamber prior to operation during concrete production batch b (bar), before CO_2 is fed into the chamber
Source of data	Project data record
Measurement procedures	Continuous monitoring of pressure, along with measurement of gas volume and temperature, for the purpose of calculating the volume under standard conditions, with the pressure gauge subject to approval by the relevant authority
Monitoring frequency	Continuous monitoring and at least monthly recording

Parameter	$T_{After,b}$ and $T_{before,b}$
Unit	K
Description	$T_{After,b}$ refer to internal temperature within the chamber after operation during concrete production batch b (K), following completion of the mineral carbonation reaction in the chamber $T_{before,b}$ refer to internal temperature within the chamber prior to operation during concrete production batch b (K), before CO_2 is injected into the chamber
Source of data	Project data record
Measurement procedures	Continuous temperature monitoring, along with gas volume and pressure measurements, for calculating standardized volume, whereby the industrial thermometer must be approved by the relevant authorities.
Monitoring frequency	Continuous monitoring and at least monthly recording

Parameter	$Q_{Cement,PJ,i,y}$
Unit	t cement
Description	The quantity of cement used in the production of concrete type i in year y
Source of data	Record the amount of cement used in concrete production from project activities
Measurement procedures	Verify the correlation between recorded cement consumption and the amount of concrete produced
Monitoring frequency	Continuous monitoring and at least monthly recording

Parameter	$Q_{Cement,PJ,Test,i}$
Unit	gram of cement
Description	Quantity of hydraulic cement utilized in the preparation of concrete type i samples under the project activity

Source of data	Record the amount of cement used in concrete production from project activities
Measurement procedures	
Monitoring frequency	Continuous monitoring and at least monthly recording

Parameter	$EC_{Capt,PJ,y}$, $EC_{LQ,PJ,y}$, $EC_{Trans,PJ,y}$, $EC_{Evap,PJ,y}$, $EC_{MineralC,PJ,y}$ และ $EC_{Trans,OB,PJ,y}$
Unit	kWh/year
Description	$EC_{Capt,PJ,y}$ refer to electricity consumption for the capture, separation of CO_2 from other gases, and collection processes in year y $EC_{Liq,PJ,y}$ refer to electricity consumption for the CO_2 liquefaction process in year y $EC_{Trans,PJ,y}$ refer to electricity consumption for CO_2 transportation under project operations in year y $EC_{Evap,PJ,y}$ refer to electricity consumption for the preparation of CO_2 in vapor phase under project operations in year y $EC_{MineralC,PJ,y}$ refer to electricity consumption in the mineral carbonation production process in year y $EC_{Trans,OB,PJ,y}$ refer to electricity consumption for transporting concrete mix materials used in the production of concrete exceeding the baseline level in year y
Source of data	Project data record
Measurement procedures	Measure electricity consumption for relevant processes using instruments such as a kWh meter or record data from monthly electricity purchase documents such as receipts. Measuring instruments must be calibrated by an accredited entity according to the manufacturer's specifications
Monitoring frequency	Continuous monitoring and at least monthly recording

Parameter	$EF_{Elec,y}$
unit	tCO_2/MWh
Description	Emission factor for electricity generation/consumption in year y
Source of data	Report on greenhouse gas emissions (Emission Factor) from electricity generation/consumption for projects and activities of greenhouse gas reduction published by TGO.
Measurement procedures	**<u>For the preparation of project proposal documents</u>** Use the latest $EF_{Elec,y}$ announced by TGO **<u>For monitoring the results of reducing greenhouse gas emissions</u>** Use the $EF_{Elec,y}$ values announced by TGO according to the year of the crediting period. However, in the case that the year of the crediting period

	does not have $EF_{Elec,y}$ values announced by TGO, use the latest $EF_{Elec,y}$ values announced by TGO in that year instead.
Monitoring frequency	-

Parameter	TDL_y
unit	-
Description	Average technical transmission and distribution losses for providing electricity in year y
Source of data	**Option 1:** Report based on monitoring data in cases where information is available on the amount of electricity supplied by the producer and the amount of electricity received by the user **Option 2:** Use the most recent value announced by TGO (value = 0.0596), which is based on data from the Thailand Energy Balance Report for the year 2023, by the Department of Alternative Energy Development and Efficiency
Measurement procedures	If Option 1 is chosen, the project developer must monitor the specified value annually throughout the monitoring period of greenhouse gas emission reductions If Option 2 is chosen, the project developer must use this value consistently throughout the monitoring period of greenhouse gas emission reduction
Monitoring frequency	To be determined once in the first year of the crediting period

Parameter	$\eta_{IPS,y}$
Unit	-
Description	Average annual efficiency of the power plant in year y (value between 0 and 1)
Source of data	Report on energy measurements and energy balance of the power plant
Measurement procedures	Measurements shall be conducted using the power plant's monitoring instruments, including: • Amount of electricity • Quantity and pressure of steam • Quantity and temperature of flue gas • Mass or volume of fossil fuels used
Monitoring frequency	-

Parameter	$TFC_{IPS,y}$
Unit	unit/year
Description	Total fossil fuel consumption by the power plant(s) supplying electricity and/or steam for use in year y
Source of data	Monitoring report and record logs of the power plant

Measurement procedures	Measure the mass or volume of fuel using the power plant's monitoring instruments
Monitoring frequency	Continuous monitoring and at least monthly recording

Parameter	$HC_{Capt,PJ,y}$ and $HC_{Evap,PJ,y}$
Unit	MJ/year
Description	$HC_{Capt,PJ,y}$ refer to heat consumption for the CO_2 capture, separation from other gases, and collection processes in year y $HC_{Evap,PJ,y}$ refer to heat consumption for the preparation of CO_2 in vapor phase in year y
Source of data	Monitoring report and record logs
Measurement procedures	Measure the quantity and pressure of steam used in the process of CO_2 capture and separation from gas using monitoring instruments, and calculate the thermal energy value, or obtain records from monthly steam purchase documents such as receipts. All monitoring instruments must be calibrated by accredited entities in accordance with the manufacturer's specifications
Monitoring frequency	Continuous monitoring and at least monthly recording

Parameter	$HG_{IPS,y}$
Unit	MJ/year
Description	Total heat output generated by power plant(s) supplying electricity and/or steam used in year y (MJ/year)
Source of data	Monitoring report and record logs of the power plant
Measurement procedures	Measure the quantity and pressure of steam using the power plant's monitoring instruments
Monitoring frequency	-

Parameter	$EG_{IPS,y}$
Unit	kWh/year
Description	Total electricity output generated by power plant(s) supplying electricity and/or steam used in year y
Source of data	Monitoring report and record logs of the power plant.
Measurement procedures	Measure electricity consumption using the power plant's monitoring instruments.
Monitoring frequency	-

Parameter	$Q_{c,Solvent,PJ,s,y}$
Unit	ton of C
Description	Carbon (C) content in solution type s for concrete mixing in year y

Source of data	Record data from the project
Measurement procedures	Results of carbon content analysis in baseline samples of concrete type n, conducted using reliable scientific instruments or analytical techniques
Monitoring frequency	Conduct sampling inspections at least once per year for each type of concrete

Parameter	$FC_{Solvent,s,y}$
Unit	ton of Solvent/year
Description	Consumption of solvent type s in year y
Source of data	Record the quantity of admixture used for concrete production
Measurement procedures	Verify the correlation between admixture volume used and the quantity of concrete produced
Monitoring frequency	Random sampling inspections shall be conducted at least once per year for each type of concrete

9.3 Data and parameters not monitored

Parameter	$Q_{C,BL,Test,i}$
Unit	gram of C/gram of project tested concrete
Description	Average carbon (C) content in samples of concrete type i from the baseline case
Source of data	Results of carbon content analysis in baseline samples of concrete type i, conducted using credible scientific instruments or analytical techniques
Applicable value	-

Parameter	R
Unit	m^3 bar K^{-1} mol^{-1}
Description	Gas constant
Source of data	Theoretical calculation value
Applicable value	8.314472×10^{-5}

Parameter	$Q_{Cement,BL,test,i}$
Unit	gram of cement
Description	Quantity of hydraulic cement utilized in the preparation of concrete type i samples under the baseline scenario
Source of data	**Option 1:** Reference value derived from recorded cement usage in concrete sample production under the facility's baseline scenario. **Option 2:**

	Reference value based on standard ratios for concrete production in project implementation, as defined by the quality specifications set by the responsible authority.
Applicable value	-

Parameter	EF_{HC}
Unit	tCO_2e/ton of cement
Description	Emission factor from hydraulic cement production
Source of data	Thai Cement Manufacturers Association
Applicable value	0.871 tCO_2/t cement

Parameter	$EF_{Cement,j}$
Unit	tCO_2e/ton of cement
Description	Emission factor of cement type j under the project activity
Source of data	Thai Cement Manufacturers Association
Applicable value	Case 1: Using Portland cement (910 $kgCO_2e$ per ton of cement) Case 2: Using hydraulic cement (871 $kgCO_2e$ per ton of cement)

Parameter	Molar mass of C in $solvent_s$
Unit	gram
Description	Mass of carbon in 1 mole (mol) of solution type s
Source of data	Molecular mass calculation through chemical equations and the periodic table, considering only carbon
Applicable value	-

Parameter	Total molar mass of $solvent_s$
Unit	gram
Description	Mass of 1 mole of solution type s
Source of data	Molecular mass calculation through chemical equations and the periodic table
Applicable value	-

Parameter	$\rho_{Solvent,s}$
Unit	kg/Liter, kg/dm^3
Description	Density of solution type s
Source of data	Chemical product labeling or description
Applicable value	-

Parameter	$EF_{SOLVENT,s,y}$
Unit	tCO_2e/ton of Solvent
Description	Emission factor of solvent type s
Source of data	Carbon Footprint of Product (CFP) data for the solution
Applicable value	-

10. Reference

1. Verified Carbon Standard

   VCS Methodology: VM0032 CO_2 Utilization in Concrete Production, Version 1.0, 5 April 2021
2. Gold Standard

   Methodology: Carbon sequestration through accelerated carbonation of concrete aggregate, Version 1.0, 7-03-2022
3. Al-Mamoori, A., Krishnamurthy, A., Rownaghi, A. A., & Rezaei, F. (2017). Carbon capture and utilization update. Energy Technology, 5(6), 834-849.
4. Hunt AJ, Sin EHK, Marriott R, Clark JH. Generation, capture, and utilization of industrial carbon dioxide. ChemSusChem 2010;3:306–22. https://doi.org/ 10.1002/cssc.200900169.
5. Ravikumar, D., Zhang, D., Keoleian, G., Miller, S., Sick, V., & Li, V. (2021). Carbon dioxide utilization in concrete curing or mixing might not produce a net climate benefit. Nature communications, 12(1), 855.
6. Monkman, S. (2018). Sustainable ready mixed concrete production using waste CO_2: A case study. *Am. Concr. Ins*, *330*, 163-174
7. Initiative, C. S. (2009). Cement industry energy and CO_2 performance: getting the numbers right. *World Business Council for Sustainable Development*.

Document information T-VER-P-METH-14-02

Version	Amendment	Entry into force	Description
01	-	24 September 2025	Initial adoption