T-VER-P-METH-14-01

CO_2 Capture and Storage in Geological Formation

Version 01

Scope: 16 – Carbon capture and storage of CO_2 in geological formation

Entry into force on 27 September 2023

1. Methodology title	CO_2 Capture and Storage in Geological Formation
2. Project type	Carbon capture, storage, and/or utilization of greenhouse gases
3. Sector and scope	16 – Carbon capture and storage of CO_2 in geological formation
4. Project outline	Project activities must be designed to capture carbon dioxide (CO_2) from a point source or from the atmosphere through Direct Air Capture (DAC) for storage in a geologic formation.
5. Applicability	Project activity is aimed to implement a process consisting of the capture and separation of CO_2 from the source, the transportation of CO_2, and the injection of CO_2 for storage into a geological formation, ensuring that: ▪ The geological storage is monitored and managed to prevent CO_2 leakage and re-release into the atmosphere in accordance with the regulatory standards of the relevant authorities. ▪ The geological storage has clearly defined boundary, size, structure, and properties to ensure that CO_2 has been stored without leakage to other site and also the geological storage is approved by the regulatory authority.
6. Project Conditions	1) CO_2 capture must be applied using the following source: ▪ The identifiable source (Point source), including: ○ Oil and natural gas production ○ Industrial processes, including fossil-fuel power plants, cement plants, steel factories, hydrogen production from natural gas reforming, and others. ▪ The atmosphere 2) Geologic formations for CO_2 storage are applicable including: ▪ Depleted petroleum reservoir ▪ Unmineable coal seam ▪ Deep saline aquifer 3) Eligible CO_2 transportation methods include pipelines, rails, trucks, and ships, which must comply with regulatory standards of the relevant authorities. 4) Project activities may involve capturing gas from a source and separating CO_2 and injecting CO_2 for storage in a geologic formation

	that is not co-located or adjacent, provided that the project proponent has the legal right to transport CO_2. 5) The process of capturing CO_2 for injection into a geologic formation must achieve a CO_2 concentration of no less than 95%. 6) CO_2 stored under the project activity may be allowed to use for Enhanced Oil Recovery (EOR). 7) The project developer must implement a verification process (methodology/equipment/location/frequency/duration) to monitor carbon dioxide leakage and migration within the geologic formation, ensuring compliance with regulatory standards set by the relevant authorities.
7. Project Starting Date	The date on which the project owner (employer) and the contractor sign the construction contract for the greenhouse gas reduction project to be developed as a T-VER project
8. Definitions	**Enhanced Oil Recovery (EOR)** refers to methods applied to increase oil production from a reservoir after natural depletion, including secondary recovery and tertiary recovery. **Secondary Recovery** refers to the process of injecting water or gas into a reservoir to displace crude oil, pushing it toward the production well. However, the injected water or gas cannot fully displace the crude oil, leaving residual oil in the reservoir after secondary recovery has been completed. **Tertiary Recovery** refers to the tertiary oil recovery process applied after primary and secondary recovery. The percentage of crude oil recovered remains low, particularly for heavy and medium crude oil, which are more difficult to extract. Therefore, tertiary recovery is implemented to further enhance oil production. Tertiary recovery methods are generally classified into three types: thermal processes, miscible processes, and chemical processes. **Independent Power Supply (IPS)** refers to a private electricity producer that generates electricity for self-use without supplying power to the grid or selling directly to customers.

	Supercritical Fluid refers to a substance at a temperature and pressure above its critical point, where it exhibits the viscosity of a gas and the density of a liquid. **Standard temperature and pressure (STP)** refer to conditions defined as a temperature of 288.15 K (15°C) and an absolute pressure of 100 kPa (1 bar).
9. Remark	

Details of T-VER methodology for

CO_2 Capture and Storage in Geological Formation

1. Greenhouse gas (GHG) emission reduction activities applied in calculation.

Table 1: Sources and types of GHGs

GHG Emissions	Sources of GHG Emission	Types of GHGs	Details of Activities Involving GHG Emissions
Baseline emission	A point source or the atmosphere	CO_2	▪ Fossil fuel combustion ▪ Limestone calcination ▪ Oil and gas from extraction
Project emission			
CO_2 capture	Emissions or leakage	CO_2	Machinery/equipment/pipeline system
	Electricity and heat generation for self-consumption	CO_2	Fossil fuel combustion in power plants located in the project boundary.
	Use of electricity and thermal energy (purchased from external sources) in the process.	CO_2	▪ Electricity generation from power plants in the transmission system ▪ Electricity and/or steam generation from IPS power plants.
CO_2 transportation	Leak out	CO_2	Machinery/equipment/pipeline system
	Electricity generation for self-consumption	CO_2	Fossil fuel combustion in power plants located in the project boundary
	Use of electricity (purchased from external sources) in processes or in electric vehicles (if applicable).	CO_2	Electricity generation from power plants in the transmission system or IPS power plants.
	Transport via maritime, road, or rail networks	CO_2	Combustion of fuel in transportation vehicles.
CO_2 injection into a geological storage	Electricity generation for self-consumption	CO_2	Fossil fuel combustion in power plants located in the project boundary
	Use of electricity (purchased from external sources) in processes	CO_2	Electricity generation from grid-connected power plants or IPS power plants

GHG Emissions	Sources of GHG Emission	Types of GHGs	Details of Activities Involving GHG Emissions
	Leak out	CO_2	Machinery, equipment, and pipeline system
	Leakage at the injection well	CO_2 และ CH_4	▪ Wellbore to storage reservoir ▪ Fugitive emissions in crude oil, produced gas, and water from the storage reservoir in cases where EOR is applied.
	Migration to other subsurface storage formations	CO_2	Injected CO_2 used for EOR migrating to other subsurface storage formations beyond the project boundary
	Leakage at the subsurface storage site	CO_2	Leakage occurring during and after CO_2 injection.
Leakage emission	Not applicable	-	-

2. Applicability and Scope of Project

Project activities must be designed to capture carbon dioxide from a point source or the atmosphere and store it in a geologic formation. The project must ensure that:

- The storage site is subject to continuous monitoring and management to prevent CO_2 leakage and re-release into the atmosphere, in accordance with regulatory standards established by the relevant authorities.
- The storage site must have clearly defined boundaries, dimensions, structural integrity, and a verified capacity to store CO_2, and it must receive approval from the regulatory authority.

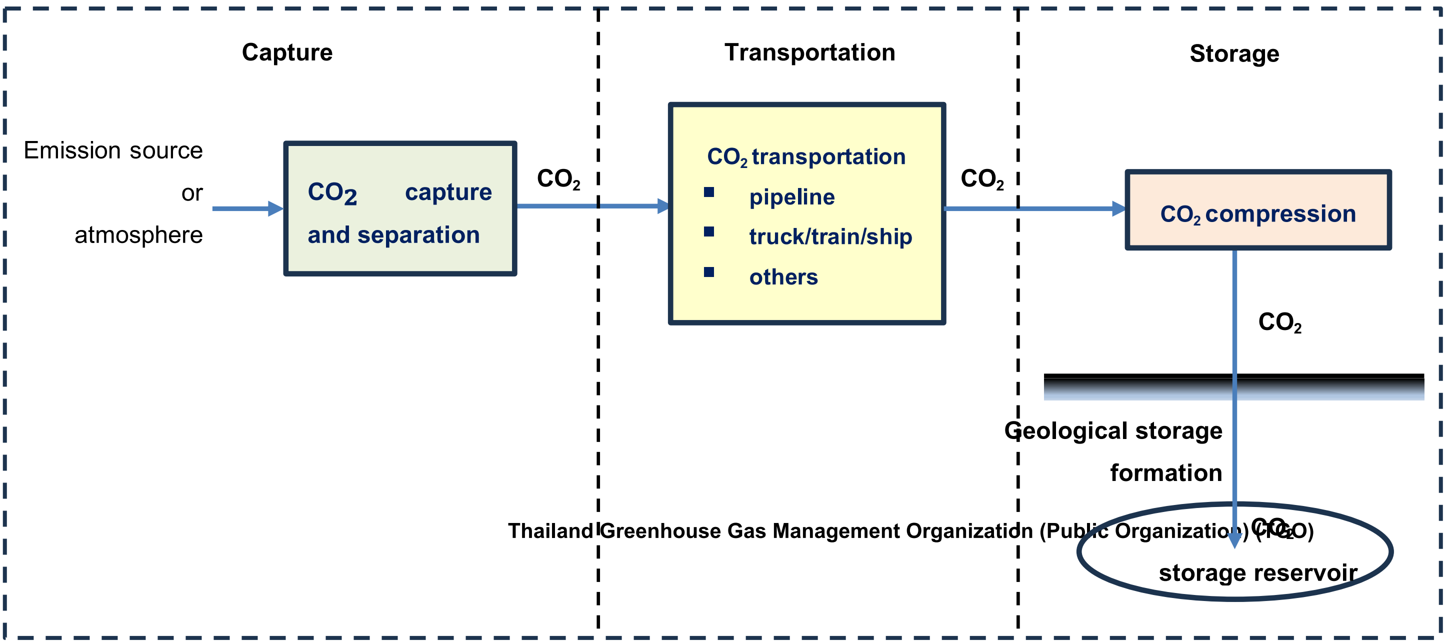

Figure 1: CO_2 capture and storage process in a geologic formation.

Project activities must consist of three main processes, as shown in Figure 1, as follows:

- **CO_2 capture and separation:** The separation of captured CO_2 from the emission source can be achieved through one of the following processes:
  - Absorption
  - Adsorption
  - Membrane separation
  - Cryogenic
- **CO_2 transportation:** The separated CO_2 is transported to the designated storage site using various methods, including:
  - Pipeline transportation
  - Land transportation (by truck, rail, or ship)
  - Marine transportation
- **CO_2 storage:** The captured CO_2, in gaseous, liquid, or supercritical fluid state, must be stored in a geologic formation with an injection well.

The project must implement a monitoring process to detect CO_2 leakage from the storage site throughout the designated crediting period and for an additional five years after the crediting period ends. This is to ensure that CO_2 remains securely stored in the geologic formation. If leakage is detected during this period, the project developer must quantify the greenhouse gas emissions resulting from CO_2 leakage at the storage site.

3. Additionality activities beyond business-as-usual (BAU) operations

The project must undergo verification of additionality beyond BAU operations by applying the "Guidelines for Demonstrating Additionality under the Thailand Voluntary Emission Reduction Program (T-VER)" as specified by TGO.

4. Baseline Scenario

The CCS project will be the first of its kind in Thailand. Therefore, the baseline data is defined as the amount of CO_2 injected into the underground storage site under standard conditions.

Note: If the number of CCS projects in Thailand increases, TGO will review and revise the baseline data determination to align with the below business-as-usual (Below BAU) approach.

5. Calculation of baseline GHG emissions

Baseline greenhouse gas emissions consider only CO_2 emissions from the designated emission sources, calculated based on the amount of CO_2 injected into the underground storage site under standard conditions.

Baseline GHG emissions can be calculated as follows:

$$BE_y = V_{Gas,INJ,y} \times (\%V/V_{CO2,INJ,y}) \times \rho_{CO2} \times AF \qquad \text{Equation (1)}$$

In which

BE_y	=	Baseline GHG emissions in year y (tCO_2e/year)
$V_{Gas,INJ,y}$	=	Volume of gas at the injection point (measured under standard conditions) in year y (m^3/year)
$\%V/V_{CO2,INJ,y}$	=	Volume fraction of CO_2 in the gas at the injection point (measured under standard conditions) in year y (value between 0 – 1)
ρ_{CO2}	=	Density of CO_2 at standard conditions = 0.00190 (tCO_2/m^3)
AF	=	Adjustment factor for baseline greenhouse gas emissions (AF = 1)

6. Calculation of GHG emissions from project operations (Project Emission)

Greenhouse gas emissions from project operations are considered based on the three main stages of project activities, including the CO_2 capture and separation process, the CO_2 transportation process, and the CO_2 injection process for underground storage.

GHG emissions from project operations can be calculated as follows:

$$PE_y = PE_{CP,y} + PE_{TR,y} + PE_{ST,y} \qquad \text{Equation (2)}$$

In which

PE_y	=	Quantity of greenhouse gas emissions from project operations in year y (tCO_2e/year)
$PE_{CP,y}$	=	Quantity of greenhouse gas emissions from project operations in the CO_2 capture and separation process in year y (tCO_2e/year)

$PE_{TR,y}$ = Quantity of greenhouse gas emissions from project operations in the CO_2 transportation process in year y (tCO_2e/year)

$PE_{ST,y}$ = Quantity of greenhouse gas emissions from project operations in the CO_2 injection process for storage in a geologic formation in year y (tCO_2e/year)

6.1 Quantity of GHG emissions from project operations in the CO_2 capture and separation process.

GHG emissions from project operations in the CO_2 capture and separation process can be calculated as follows:

$$PE_{CP,y} = PE_{CP,FF,y} + PE_{CP,Elec,y} + PE_{CP,IPS,y} \quad \text{Equation (3)}$$

In which

$PE_{CP,FF,y}$ = Quantity of GHG emissions from project operations for fossil fuel combustion in the CO_2 capture and separation process in year y (tCO_2e/year)

$PE_{CP,Elec,y}$ = Quantity of GHG emissions from project operations for electricity consumption from the power grid in the CO_2 capture and separation process in year y (tCO_2e/year)

$PE_{CP,IPS,y}$ = Quantity of GHG emissions from project operations for electricity and/or steam consumption from IPS power plants in the CO_2 capture and separation process in year y (tCO_2e/year)

6.1.1 Quantity of GHG emissions from project operations for fossil fuel combustion in the CO_2 capture and separation process.

Greenhouse gas emissions from fossil fuel combustion in the CO_2 capture and separation process, such as heat production for the regeneration of absorbents or adsorbents, and electricity and heat generation for the CO_2 capture and separation process (excluding externally purchased energy), shall be calculated using the latest version of T-VER-P-TOOL-02-01, "Calculation of Greenhouse Gas Emissions from Fossil Fuel Combustion in Project Operations or Outside the Project Boundary".

6.1.2 Quantity of GHG emissions from project operations for electricity consumption from the power grid in the CO_2 capture and separation process

GHG emissions from purchased electricity consumption from the power grid in the CO_2 capture and separation process can be calculated based on electricity consumption, the GHG emission factor for electricity generation/use, and the power loss factor in the electricity grid, as shown in the following equation:

$$PE_{CP,Elec,y} = EC_{CP,PJ,y} \times EF_{Elec,y} \times (1 + TDL_y) \times 10^{-3} \quad \text{Equation (4)}$$

In which

$EC_{CP,PJ,y}$ = Electricity consumption in the CO_2 capture and separation process in year y (kWh/year)

$EF_{Elec,y}$ = GHG emission factor for electricity generation/use in year y (tCO_2/MWh)

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

6.1.3 Quantity of GHG emissions from project operations for electricity and/or steam consumption from IPS power plants in the CO_2 capture and separation process

GHG emissions from purchased electricity and/or steam from IPS power plants for use in the CO_2 capture and separation process are determined based on fossil fuel combustion using an allocation approach, as shown in Equation (5). The resulting values are then used to calculate greenhouse gas emissions by applying the latest version of T-VER-P-TOOL-02-01, "Calculation of Greenhouse Gas Emissions from Fossil Fuel Combustion in Project Operations or Outside the Project Boundary"

$$FC_{CP,IPS,y} = (1/\eta_{IPS,y}) \times TFC_{IPS,y} \times \left[\frac{(HC_{CP,y}+3.6\times EC_{CP,PJ,y})}{(HG_{IPS,y}+3.6\times EG_{IPS,y})}\right] \quad \text{Equation (5)}$$

In which

$FC_{CP,IPS,y}$	=	Quantity of fossil fuel consumption for purchased electricity and/or heat used in the CO_2 capture and separation process in year y (unit/year)
$TFC_{IPS,y}$	=	Total fossil fuel consumption of the power plant supplying purchased electricity and/or steam in year y (unit/year)
$HC_{CP,PJ,y}$	=	Quantity of heat used in the CO_2 capture and separation process in year y (MJ/year)
$EC_{CP,PJ,y}$	=	Quantity of electricity consumption in the CO_2 capture and separation process in year y (kWh/year)
$HG_{IPS,y}$	=	Total heat production of the power plant supplying purchased electricity and/or steam in year y (MJ/year)
$EG_{IPS,y}$	=	Total electricity production of the power plant supplying purchased electricity and/or steam in year y (kWh/year)
$\eta_{IPS,y}$	=	Annual average efficiency of the power plant in year y (value between 0 – 1)

6.2 Quantity of GHG emissions from project operations in the CO_2 transportation process

GHG emissions from project operations in the transportation of CO_2, captured and separated in the CO_2 capture process, to the CO_2 injection process for storage in a geologic formation can be calculated as follows:

$$PE_{TR,y} = PE_{TR,FF,y} + PE_{TR,Elec,y} \quad \text{Equation (6)}$$

In which

$PE_{TR,y}$	=	Quantity of GHG emissions from project operations in the CO_2 transportation process in year y (tCO_2e/year)
$PE_{TR,FF,y}$	=	Quantity of GHG emissions from project operations for fossil fuel combustion in machinery/equipment/vehicles used for CO_2 transportation in year y (tCO_2e/year)
$PE_{TR,Elec,y}$	=	Quantity of GHG emissions from project operations for electricity consumption from the power grid for CO_2 transportation through pipelines in year y (tCO_2e/year)

6.2.1 Quantity of GHG emissions from project operations for fossil fuel combustion in machinery, equipment, and vehicles used for CO_2 transportation.

GHG emissions from fossil fuel combustion in the CO_2 transportation process are determined based on fuel consumption in various vehicles used for transporting CO_2 from the CO_2 capture and separation process to the CO_2 injection process for storage in a geologic formation. This also includes emissions from fuel used in machinery or equipment for pressure enhancement (if applicable). GHG emissions shall be calculated using the latest version of T-VER-P-TOOL-02-01, "Calculation of Greenhouse Gas Emissions from Fossil Fuel Combustion in Project Operations or Outside the Project Boundary".

6.2.2 Quantity of GHG emissions from project operations for electricity consumption from the power grid for CO_2 transportation through pipelines.

GHG emissions from purchased electricity consumption from the power grid in the CO_2 transportation process take into account machinery or equipment used for CO_2 pressure enhancement in its gaseous state for pipeline transportation or for cooling CO_2 to convert it into a liquid state for transportation by vehicles. This also includes the use of electric vehicles (EVs) for CO_2 transportation (if applicable). The emissions can be calculated using the following equation:

$$PE_{TR,Elec,y} = EC_{TR,PJ,y} \times EF_{Elec,y} \times (1 + TDL_y) \times 10^{-3} \quad \text{Equation (7)}$$

In which

$EC_{TR,PJ,y}$ = Quantity of electricity consumption in the CO_2 transportation process in year y (kWh/year)

$EF_{Elec,y}$ = GHG emission factor for electricity generation/use in year y (tCO_2/MWh)

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

In the case of electricity purchased from an IPS power plant, GHG emissions from such electricity consumption are determined based on fossil fuel combustion at the power plant using an allocation approach, as shown in Equation (8). The resulting values are then used to calculate greenhouse gas emissions by applying the latest version of T-VER-P-TOOL-02-01, "Calculation of Greenhouse Gas Emissions from Fossil Fuel Combustion in Project Operations or Outside the Project Boundary".

$$FC_{TR,IPS,y} = (1/\eta_{IPS,y}) \times TFC_{IPS,y} \times \left[\frac{(3.6 \times EC_{TR,PJ,y})}{(HG_{IPS,y} + 3.6 \times EG_{IPS,y})}\right] \quad \text{Equation (8)}$$

In which

$FC_{TR,IPS,y}$ = Quantity of fossil fuel consumption for purchased electricity used in the CO_2 transportation process in year y (unit/year)

$TFC_{IPS,y}$ = Total fossil fuel consumption of the power plant supplying purchased electricity in year y (unit/year)

$EC_{TR,PJ,y}$ = Quantity of electricity consumption in the CO_2 transportation process in year y (kWh/year)

$HG_{IPS,y}$ = Total heat production of the power plant supplying purchased electricity in year y (MJ/year)

$EG_{IPS,y}$ = Total electricity production of the power plant supplying purchased electricity in year y (kWh/year)

$\eta_{IPS,y}$ = Annual average efficiency of the power plant in year y (value between 0 – 1)

6.3 Quantity of GHG emissions from project operations in the CO_2 injection process for storage in a geologic formation.

GHG emissions from project operations in the CO_2 injection process through the injection well for storage in a geologic formation can be calculated as follows:

$$PE_{ST,y} = PE_{ST,FF,y} + PE_{ST,Elec,y} + PE_{ST,Fugtive,y} + PE_{ST,EOR,y} + PE_{ST,Leak,y} \quad \text{Equation (9)}$$

In which

$PE_{ST,y}$ = Quantity of GHG emissions from project operations in the CO_2 injection process for storage in a geologic formation in year y (tCO_2e/year)

$PE_{ST,FF,y}$ = Quantity of GHG emissions from project operations for fossil fuel combustion in the CO_2 injection process for storage in a geologic formation in year y (tCO_2e/year)

$PE_{ST,Elec,y}$ = Quantity of GHG emissions from project operations for electricity consumption from the power grid in the CO_2 injection process for storage in a geologic formation in year y (tCO_2e/year)

$PE_{ST,Fugtive,y}$ = Quantity of GHG emissions from project operations for CO_2 and CH_4 leakage at the injection well in year y (tCO_2e/year)

$PE_{ST,EOR,y}$ = Quantity of GHG emissions from project operations for CO_2 migration used in EOR to other subsurface storage formations beyond the project boundary in year y (tCO_2e/year)

$PE_{ST,Leak,y}$ = Quantity of GHG emissions from project operations for CO_2 leakage from the storage site under project activities into the atmosphere in year y (tCO_2e/year)

6.3.1 Quantity of GHG emissions from project operations for fossil fuel combustion in the CO_2 injection process for storage in a geologic formation.

GHG emissions from fossil fuel combustion in machinery or equipment for CO_2 pressurization for injection (if applicable) shall be calculated using the latest version of T-VER-P-TOOL-02-01, "Calculation of Greenhouse Gas Emissions from Fossil Fuel Combustion in Project Operations or Outside the Project Boundary".

6.3.2 Quantity of GHG emissions from project operations for electricity consumption from the power grid in the CO_2 injection process for storage in a geologic formation.

GHG emissions from purchased electricity consumption from the power grid in machinery or equipment for CO_2 pressurization for injection can be calculated using the following equation:

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

In which

$EC_{ST,PJ,y}$ = Quantity of electricity consumption in the CO_2 injection process for storage in a geologic formation in year y (kWh/year)

$EF_{Elec,y}$ = GHG emission factor for electricity generation/use in year y (tCO_2/MWh)

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

In the case of electricity purchased from an IPS power plant, GHG emissions from such electricity consumption are determined based on fossil fuel combustion at the power plant using an allocation approach, as shown in Equation (11). The resulting values are then used to calculate greenhouse gas emissions by applying the latest version of T-VER-P-TOOL-02-01, "Calculation of Greenhouse Gas Emissions from Fossil Fuel Combustion in Project Operations or Outside the Project Boundary".

$$FC_{ST,IPS,y} = (1/\eta_{IPS,y}) \times TFC_{IPS,y} \times \left[\frac{(3.6 \times EC_{ST,PJ,y})}{(HG_{IPS,y} + 3.6 \times EG_{IPS,y})}\right] \quad \text{Equation (11)}$$

In which

$FC_{ST,IPS,y}$ = Quantity of fossil fuel consumption for purchased electricity in year y (unit/year)

$TFC_{IPS,y}$ = Total fossil fuel consumption of the power plant supplying purchased electricity in year y (unit/year)

$EC_{ST,PJ,y}$ = Quantity of electricity consumption in the CO_2 injection process for storage in a geologic formation in year y (kWh/year)

$HG_{IPS,y}$ = Total heat production of the power plant supplying purchased electricity in year y (MJ/year)

$EG_{IPS,y}$ = Total electricity production of the power plant supplying purchased electricity in year y (kWh/year)

$\eta_{IPS,y}$ = Annual average efficiency of the power plant in year y (value between 0 – 1)

6.3.3 Quantity of GHG emissions from project operations for CO_2 and CH_4 leakage at the injection well.

GHG emissions from project operations at the injection well are considered in two parts, as shown in the following equation:

$$PE_{ST,Fugitive,y} = PE_{ST,Fugitive,Equip,y} + PE_{ST,Fugitive,EOR,y} \quad \text{Equation (12)}$$

In which

$PE_{ST,Fugitive,Equip,y}$ = Quantity of GHG emissions from project operations for CO_2 leakage at the injection well in year y (tCO_2e/year)

$PE_{ST,Fugitive,EOR,y}$ = Quantity of GHG emissions from project operations for CO_2 and CH_4 leakage from crude oil or produced gas at the storage reservoir in cases where EOR is applied in year y (tCO_2e/year)

6.3.3.1 Quantity of GHG emissions from project operations for CO_2 leakage at the injection well.

GHG emissions from project operations at the injection well occur in the pipeline system after passing through pressurization equipment and along the wellbore to the storage reservoir. These emissions are calculated using the following equation

$$PE_{ST,Fugitive,Equip,y} = \sum_j \left(EF_{Well,j} \times h_{Well,j}\right) \times \left(\%V/V_{CO2,INJ,y}\right) \times \rho_{CO2} \times 10^{-3} \quad \text{Equation (13)}$$

In which

$EF_{Well,j}$ = Emission factor for leakage at injection well j (m^3/hour)

$h_{Well,j}$ = Total operating hours of machinery and equipment for CO_2 injection at injection well j in year y (hours)

$\%V/V_{CO2,INJ,y}$ = Volume fraction of CO_2 in the gas at the injection point (measured under standard conditions) in year y (value between 0 – 1)

ρ_{CO2} = Density of CO_2 at standard conditions = 0.00190 (tCO_2/m^3)

j = Injection well j

6.3.3.2 Quantity of GHG emissions from project operations for CO_2 and CH_4 leakage from crude oil or produced gas at the storage reservoir in cases where EOR is applied.

GHG emissions from project operations for CO_2 and CH_4 leakage from crude oil or produced gas at the storage reservoir, including CO_2 and CH_4 dissolved in water co-produced with crude oil or gas in cases where EOR is applied, can be calculated using the following equation:

$$\begin{aligned} PE_{ST,Fugitive,EOR,y} = & V_{Gas,y} \times \left[\left(\%V/V_{CO2,Gas,y}\right) \times \rho_{CO2} + \left(\%V/V_{CH4,Gas,y}\right) \times \rho_{CH4} \times GWP_{CH4}\right] \times 10^{-3} \\ & + m_{Water,y} \times \left[\left(\%W/W_{CO2,Water,y}\right) + \left(\%W/W_{CH4,Water,y}\right) \times GWP_{CH4}\right] \\ & + m_{Oil,y} \times \left[\left(\%W/W_{CO2,Oil,y}\right) + \left(\%W/W_{CH4,Oil,y}\right) \times GWP_{CH4}\right] \quad \text{Equation (14)} \end{aligned}$$

In which

$V_{Gas,y}$ = Quantity of gas produced from EOR and sold to customers in year y (m^3/year)

$\%V/V_{CO2,Gas,y}$ = Volume fraction of CO_2 in the gas produced from EOR and sold to customers (measured under standard conditions) in year y (value between 0 – 1)

$\%V/V_{CH4,Gas,y}$ = Volume fraction of CH_4 in the gas produced from EOR and sold to customers (measured under standard conditions) in year y (value between 0 – 1)

ρ_{CO2} = Density of CO_2 at standard conditions = 0.00190 (tCO_2/m^3)

ρ_{CH4} = Density of CH_4 at standard conditions = 0.00717 (tCH_4/m^3)

GWP_{CH4} = Global warming potential (GWP) of methane (tCO_2/tCH_4)

$m_{Water,y}$ = Quantity of water produced during crude oil or gas production from EOR and sold to customers in year y (m^3/year)

$\%W/W_{CO2,Water,y}$ = Mass fraction of CO_2 per unit mass of water produced during EOR in year y (value between 0 – 1)

$\%W/W_{CH4,Water,y}$ = Mass fraction of CH_4 per unit mass of water produced during EOR in year y (value between 0 – 1)

$m_{Oil,y}$ = Quantity of crude oil produced from EOR and sold to customers in year y (m^3/year)

$\%W/W_{CO2,Oil,y}$ = Mass fraction of CO_2 per unit mass of crude oil produced from EOR in year y (value between 0 – 1)

$\%W/W_{CH4,Oil,y}$ = Mass fraction of CH_4 per unit mass of crude oil produced from EOR in year y (value between 0 – 1)

6.3.4 Quantity of GHG emissions from project operations for CO_2 migration used in EOR to subsurface storage formations beyond the project boundary

GHG emissions from project operations for CO_2 migration used in EOR to subsurface storage formations beyond the project boundary can be calculated using the following equation:

$$PE_{ST,EOR,y} = V_{CO2,EOR,y} \times \rho_{CO2} \times 10^{-3} \qquad \text{Equation (15)}$$

In which

$V_{CO2,EOR,y}$ = Volume of CO_2 used in EOR and migrating to subsurface storage formations beyond the project boundary under standard conditions in year y (m^3/year)

ρ_{CO2} = Density of CO_2 at standard conditions = 0.00190 (tCO_2/m^3)

6.3.5 Quantity of GHG emissions from project operations for CO_2 leakage from the storage site under project activities into the atmosphere.

In the event of detected leakage from the storage site during project activities, GHG emissions from CO_2 leakage in the storage site are considered in two phases: the CO_2 injection phase and the post-injection phase. The emissions can be calculated using the following equation:

$$PE_{ST,Leak,y} = m_{CO2,INJ,y} + m_{CO2,Post\text{-}INJ,y}$$ Equation (16)

In which

$m_{CO2,INJ,y}$ = Quantity of CO_2 leaked from the storage site during the CO_2 injection phase for storage in a geologic formation under standard conditions in year y (tCO_2/year)

$m_{CO2,Post\text{-}INJ,y}$ = Quantity of CO_2 leaked from the storage site after the CO_2 injection phase under standard conditions in year y (tCO_2/year)

7. Calculation of GHG emissions outside the project boundary.

No applicable activities.

8. Calculation of GHG emission reduction.

The reduction in GHG emissions from the project can be calculated as follows

$$\mathbf{ER_y = BE_y - PE_y - LE_y} \qquad \text{Equation (17)}$$

In which

ER_y = GHG emission reductions in year y (tCO_2e/year)

BE_y = GHG emissions from the baseline scenario in year y (tCO_2e/year)

PE_y = GHG emissions from project operations in year y (tCO_2e/year)

LE_y = GHG emissions outside the project boundary in year y (tCO_2e/year)

9. Project Monitoring (Monitoring Plan)

9.1 Monitoring Procedures

1) The project developer shall describe and specify the monitoring procedures for project activity data or the verification of all measured results in the project proposal document. This should include the types of measurement instruments used, the personnel responsible for monitoring and data verification, instrument calibration (if applicable), and the quality assurance and quality control (QA/QC) procedures. In cases where the methodology provides different options, such as the use of default values or on-site measurements, the project developer must indicate which option will be applied. Additionally, the installation, maintenance, and calibration of measurement instruments should be carried out in accordance with the equipment manufacturer's recommendations and in compliance with national or international standards, such as IEC or ISO.

2) All data collected as part of the GHG reduction monitoring process should be stored in electronic format and retained for a period in accordance with the guidelines set by TGO or the organization's quality management system, provided that the retention period is not shorter

than that specified by TGO. Additionally, data accuracy should be verified in compliance with the monitoring methods specified for the parameters listed in Table 9.3.

9.2 Non-Monitored Parameters

Parameter	$EF_{Well,j}$
Unit	m^3/hour
Definition	Emission factor for leakage at injection well j
Data Source	**Option 1:** Reference values from registered CCS project activities under other carbon credit mechanisms. If multiple reference values are available, the highest reference value shall be considered. **Option 2:** Reference values from peer-reviewed published research articles or documents from recognized institutions within the relevant industry sector.

9.3 Monitored Parameters

Parameter	$V_{Gas,INJ,y}$
Unit	m^3/year
Definition	Gas volume at the injection point into the storage reservoir (measured under standard conditions) in year y
Data Source	Flow meter
Monitoring Method	Continuous gas volume measurement, combined with pressure and temperature monitoring to calculate the volume under standard conditions, with the flow meter requiring approval from the relevant authority.
Monitoring Frequency	Continuous monitoring with records kept at least on a monthly basis.

Parameter	$\%V/V_{CO2,INJ,y}$
Unit	-
Definition	Volume fraction of CO_2 in the gas at the injection point into the storage reservoir (measured under standard conditions) in year y
Data Source	Gas Chromatography
Monitoring Method	Continuous volume fraction analysis, combined with pressure and temperature monitoring to calculate the fraction under standard conditions, with the Gas Chromatography system requiring approval from the relevant authority.
Monitoring Frequency	Continuous monitoring with records kept at least on a monthly basis.

Parameter	$EC_{CP,PJ,y}$, $EC_{TR,PJ,y}$ and $EC_{ST,PJ,y}$
Unit	kWh/year
Definition	$EC_{CP,PJ,y}$ is the quantity of electricity consumption in the CO_2 capture and separation process in year y $EC_{TR,PJ,y}$ is the quantity of electricity consumption in the CO_2 transportation process in year y

	$EC_{ST,PJ,y}$ is the quantity of electricity consumption in the CO_2 injection process for storage in a geologic formation in year y
Data Source	Measurement instruments or electricity purchase reports
Monitoring Method	Electricity consumption for relevant processes shall be measured using monitoring instruments such as kWh meters or recorded from monthly electricity purchase documents (e.g., invoices or receipts). The measurement instruments must be calibrated by an accredited entity in accordance with the manufacturer's specifications.
Monitoring Frequency	Continuous monitoring with records kept at least on a monthly basis.

Parameter	$EF_{Elec,y}$
Unit	tCO_2/MWh
Definition	GHG emission factor for electricity generation/use in year y
Data Source	The GHG emission factor for electricity generation/use shall be based on the values published by TGO for GHG reduction projects and activities.
Monitoring Method	**For project proposal documentation** The most recent $EF_{Elec,y}$ value published by TGO shall be used. **For monitoring of GHG emission reductions** The $EF_{Elec,y}$ value published by TGO for the corresponding calendar year of the crediting period shall be applied. If the $EF_{Elec,y}$ value for the crediting period year has not yet been published by TGO, the most recently published $EF_{Elec,y}$ value shall be used for that year instead.

Parameter	TDL_y
Unit	-
Definition	Average technical transmission and distribution losses for providing electricity in year y
Data Source	**Option 1:** Measurement report, applicable in cases where data on electricity supplied by the producer and electricity received by the end user are available. **Option 2:** Use of a default value of 0.03 (3%)
Monitoring Method	▪ If Option 1 is selected, the project developer must monitor this value annually throughout the monitoring period for GHG emission reductions. ▪ If Option 2 is selected, the project developer must apply this value consistently throughout the monitoring period for GHG emission reductions.
Monitoring Frequency	-

Parameter	$TFC_{IPS,y}$
Unit	unit/year

Definition	Total fossil fuel consumption of the power plant supplying purchased electricity and/or steam in year y
Data Source	Power plant measurement reports and records
Monitoring Method	The mass or volume of fuel shall be measured using the power plant's monitoring instruments.
Monitoring Frequency	Continuous monitoring with records kept at least on a monthly basis.

Parameter	$HG_{IPS,y}$
Unit	MJ/year
Definition	Total heat production of the power plant supplying purchased electricity and/or steam in year y
Data Source	Power plant measurement reports and records
Monitoring Method	The quantity and pressure of steam shall be measured using the power plant's monitoring instruments.
Monitoring Frequency	-

Parameter	$EG_{IPS,y}$
Unit	kWh/year
Definition	Total electricity production of the power plant supplying purchased electricity and/or steam in year y.
Data Source	Power plant measurement reports and records
Monitoring Method	The electricity quantity shall be measured using the power plant's monitoring instruments.
Monitoring Frequency	-

Parameter	$\eta_{IPS,y}$
Unit	-
Definition	Annual average efficiency of the power plant in year y (value between 0 – 1)
Data Source	Power plant measurement reports and energy balance analysis.
Monitoring Method	The parameters shall be measured using the power plant's monitoring instruments as follows: ● Electricity quantity ● Steam quantity and pressure ● Exhaust gas quantity and temperature at the stack ● Mass or volume of fossil fuel consumed
Monitoring Frequency	-

Parameter	$HC_{CP,PJ,y}$

Unit	MJ/year
Definition	Quantity of heat used in the CO_2 capture and separation process in year y.
Data Source	Measurement reports and records
Monitoring Method	Measure the quantity and pressure of steam used in the CO_2 capture and separation process using monitoring instruments and calculate the corresponding heat quantity, or record the data from monthly steam purchase documents, such as invoices. The monitoring instruments must be calibrated by an accredited entity in accordance with the manufacturer's specifications.
Monitoring Frequency	-

Parameter	$h_{Well,j}$
Unit	hours
Definition	Total operating hours of machinery and equipment for CO_2 injection at injection well j in year y.
Data Source	Recording reports
Monitoring Method	Direct verification from operating hours or estimation based on downtime records of CO_2 injection machinery and equipment.
Monitoring Frequency	Continuous monitoring with records kept at least on a monthly basis.

Parameter	$V_{Gas,y}$
Unit	m^3/year
Definition	Quantity of gas produced from EOR and sold to customers in year y.
Data Source	Flow meter
Monitoring Method	Continuous gas volume measurement, combined with pressure and temperature monitoring, to calculate the volume under standard conditions. The flow meter must comply with relevant industry standards (if applicable) and be calibrated in accordance with the manufacturer's specifications.
Monitoring Frequency	Continuous monitoring with records kept at least on a monthly basis.

Parameter	$m_{Water,y}$ and $m_{Oil,y}$
Unit	ton/year
Definition	$m_{Water,y}$ is the mass of water produced during crude oil or gas production from EOR and sold to customers in year y. $m_{Oil,y}$ is the mass of crude oil produced from EOR and sold to customers in year y.
Data Source	Flow meter
Monitoring Method	Continuous volume measurement, with the flow meter complying with relevant industry standards (if applicable) and calibrated in accordance with the manufacturer's specifications.

Monitoring Frequency	Continuous monitoring with records kept at least on a monthly basis.

Parameter	$\%V/V_{CO2,Gas,y}$ and $\%V/V_{CH4,Gas,y}$
Unit	-
Definition	$\%V/V_{CO2,Gas,y}$ is the volume fraction of CO_2 in the gas produced from EOR and sold to customers (measured under standard conditions) in year y $\%V/V_{CH4,Gas,y}$ is the volume fraction of CH_4 in the gas produced from EOR and sold to customers (measured under standard conditions) in year y.
Data Source	Measurement reports
Monitoring Method	Perform laboratory composition analysis.
Monitoring Frequency	Continuous monitoring with records kept at least on a monthly basis.

Parameter	$\%W/W_{CO2,Water,y}$, $\%W/W_{CH4,Water,y}$, $\%W/W_{CO2,Oil,y}$ and $\%W/W_{CH4,Oil,y}$
Unit	-
Definition	$\%W/W_{CO2,Water,y}$ is the mass fraction of CO_2 per unit mass of water produced during EOR in year y. $\%W/W_{CH4,Water,y}$ is the mass fraction of CH_4 per unit mass of water produced during EOR in year y $\%W/W_{CO2,Oil,y}$ is the mass fraction of CO_2 per unit mass of crude oil produced from EOR in year y $\%W/W_{CH4,Oil,y}$ is the mass fraction of CH_4 per unit mass of crude oil produced from EOR in year y.
Data Source	Measurement reports
Monitoring Method	Perform laboratory composition analysis.
Monitoring Frequency	Continuous monitoring with records kept at least on a monthly basis.

Parameter	GWP_{CH4}
Unit	tCO_2/ tCH_4
Definition	Global Warming Potential (GWP) of methane.
Data Source	Utilize data from the IPCC Assessment Report, developed by the Intergovernmental Panel on Climate Change (IPCC) and officially published by TGO.
Monitoring Method	**For project proposal documentation** The most recent GWP_{CH4} value, as published by TGO, shall be used. **For monitoring GHG emission reductions** The GWP_{CH4} value published by TGO for the respective crediting period shall be applied for GHG quantification.
Monitoring Frequency	-

Parameter	$V_{CO2,EOR,y}$
Unit	m^3/year
Definition	Volume of CO_2 used for EOR and migrating to an underground storage reservoir outside the project boundary, measured under standard conditions, in year y.
Data Source	Calculation results from a mathematical model.
Monitoring Method	Utilize a mathematical reservoir model in conjunction with data from: ▪ CO_2 pressure in the storage reservoir ▪ Well logging ▪ Geophysical data obtained through seismic survey measurements
Monitoring Frequency	Monitor until no CO_2 leakage to underground storage reservoirs outside the project boundary is detected.

Parameter	$m_{CO2,INJ,y}$ and $m_{CO2,Post\text{-}INJ,y}$
Unit	tCO_2/year
Definition	$m_{CO2,INJ,y}$ is the volume of CO_2leaked from the storage reservoir during the injection phase into the geologic formation, measured under standard conditions, in year y. $m_{CO2,Post\text{-}INJ,y}$ is the volume of CO_2 leaked from the storage reservoir after the completion of the injection phase, measured under standard conditions, in year y.
Data Source	Calculation results from a mathematical model.
Monitoring Method	Utilize a mathematical reservoir model in conjunction with data from: ▪ CO_2 pressure in the storage reservoir ▪ Well logging ▪ Geophysical data obtained through seismic survey measurements
Monitoring Frequency	Monitor until no CO_2 leakage is detected in the storage reservoir.

References

1. American Carbon Registry
   Methodology for the quantification, monitoring, reporting and verification of greenhouse gas emissions reductions and removals from carbon capture and storage projects VERSION 1.1, September 2021
2. IPCC Special Report on Carbon Dioxide Capture and Storage, 2005.

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