QUANTIFICATION PROTOCOL FOR GEOLOGICAL SEQUESTRATION THROUGH ENHANCED OIL RECOVERY USING CO_2 INJECTION:

ABRIDGED

Submitted to:

Alberta Environment

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Disclaimer

The following document presents an abridged version of the Geological Sequestration through Enhanced Oil Recovery using CO_2 Injection protocol prepared for Alberta Environment and Alberta Agriculture, Food and Rural Development which has completed an initial round of technical review. This document has been prepared as a means of supporting a broader stakeholder consultation process. As such, this document should not be used as a quantification protocol.

The full-length protocol is largely based on the *CO2-EOR Offset Quantification Protocol* dated September, 2006. This document was prepared by EnergyINet Inc. and the Alberta Research Council Inc. for submission to Alberta Environment.

Table of Contents

List of Figures

List of Tables

1.0 Project and Methodology Scope and Description

This quantification protocol is applicable to the quantification of direct and indirect reductions of greenhouse gas (GHG) emissions resulting from the geological sequestration of waste gas streams containing greenhouse gases as part of enhanced oil recovery (EOR) schemes. The protocol quantifies emission reductions created by the capture, processing, transport, injection, recirculation and geological sequestration of waste gases from the fossil fuel industry or other industrial processes. **FIGURE 1.1** offers a project element life cycle chart for a typical project.

This protocol applies to projects where the injected gases are from anthropogenic sources and would otherwise have been vented to atmosphere. Formation carbon dioxide that would otherwise have been vented to atmosphere may also be included where it was produced as a by-product of coal bed methane, natural gas or oil production. This protocol serves as a generic 'recipe' for project proponents to follow in order to meet the measurement, monitoring and GHG quantification requirements.

The baseline condition for projects applying this protocol is defined as the operating condition prior to the start-up or expansion of the injection operation. The baseline is project-specific but would be anticipated to include the venting or flaring of the greenhouse gases contained within source gas streams either at the capture point or as part of processing, and where applicable, the operation of the fuel production systems without injection and geological sequestration. For Source Type B emissions, the capture point is defined at the site where capture systems would be deployed under the project condition **FIGURE 1.2** offers a element life cycle chart for a typical baseline configuration.

The approach to quantifying the baseline will be calculation based as there are suitable data available for the applicable baseline condition that can provide reasonable certainty. The baseline scenario for this protocol is dynamic as the volume of gas injected would be expected to change materially from project to project.

For illustration purposes, the process flow diagrams for the baseline and project condition include two types of source gases:

- **Source Type A** - applicable to projects where gas capture and processing are part of the normal operating practice for the facility, and the EOR project has been implemented to utilize the processed gas. This source type is anticipated to apply to solution gas capture and processing in the fossil fuel production industry.
- **Source Type B** - applicable to projects where gas capture and processing are not normally undertaken (and thus are not described in the baseline process flow diagram), but are added to the system in order to utilize waste gases for EOR. Source Type B is anticipated to apply to industrial processes outside of the fossil fuel production industry.

For EOR projects that use more than one source of CO_2, the project proponent must identify the type of each source and perform the applicable quantification calculations for each source.

FIGURE 1.1: Project Element Life Cycle Chart

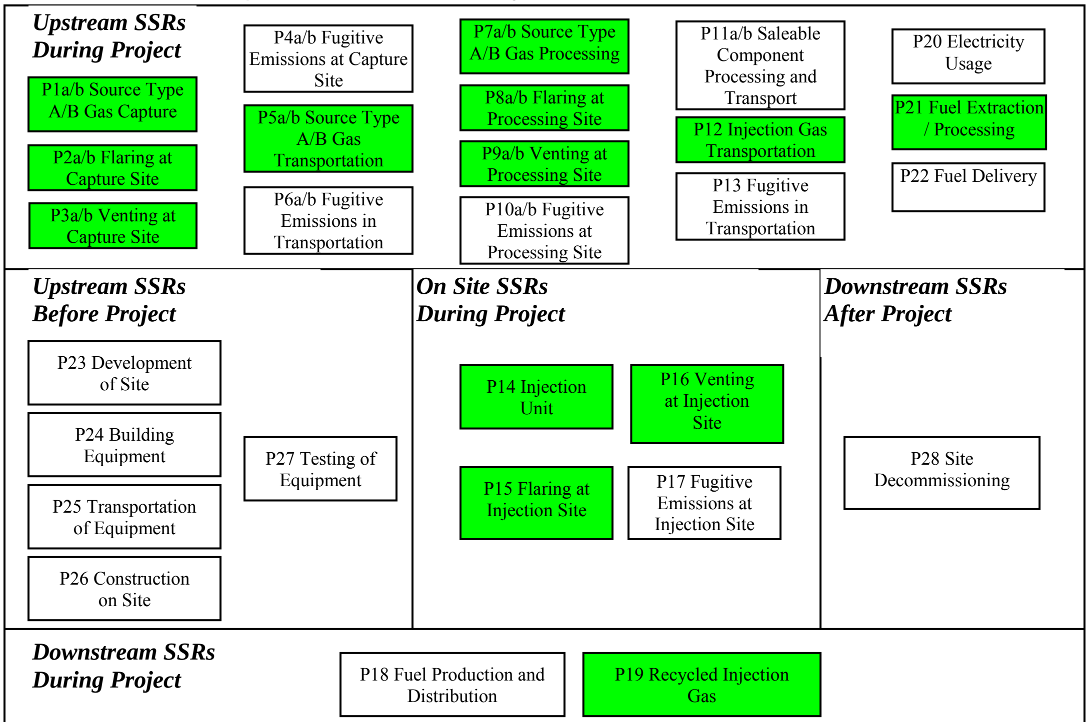
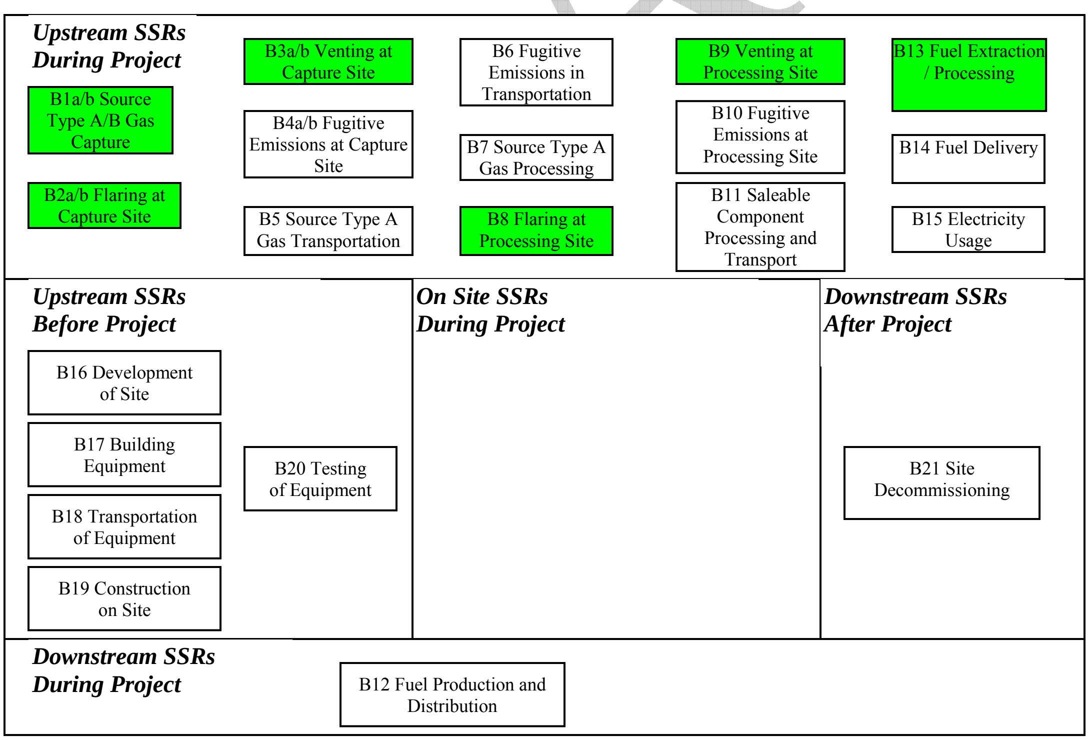


FIGURE 1.2: Baseline Element Life Cycle Chart



* Sources, sinks and reservoirs selected for measurement and monitoring under this protocol are highlighted.

To demonstrate that a project meets the requirements under this protocol, the project proponent must supply sufficient evidence to demonstrate that:

1. The storage project results in removal of emissions that would otherwise have been released to the atmosphere as indicated by an attestation from the project proponent and project schematics;
2. A geological assessment of the project area has been completed and provides sufficient confidence seepage of the injected gas will not occur;
3. The EOR system must be managed for zero leakage, as demonstrated by a project management plan and site monitoring systems as described below;
4. Site monitoring systems must ensure containment of the gas stream within the reservoir as demonstrated by a site monitoring plan;
5. Metering of gas volumes takes place as close to the injection point as is reasonable to address the potential for fugitive emissions as demonstrated by a project schematics;
6. A post-abandonment monitoring plan is in place to ensure that the injected gas is maintained within the reservoir once the EOR project is no longer in operation;
7. The quantification of reductions achieved by the project is based on actual measurement and monitoring (except where indicated in this protocol) as indicated by the proper application of this protocol.

Flexibility in applying the quantification protocol is provided to project developers in three ways:

1. Not all parameters are applicable to all EOR systems. Those sources and sinks that are not applicable will be excluded as their input variables will be zeros. As such, the project proponent can exclude sources and sinks that are not applicable to their project with reasonable justification;
2. This protocol may be applied to projects where an existing injection program is being expanded to include additional capacity. In the case of a project expansion, the proponent may consider the additional capacity as a new project. Alternatively, the project proponent may include the previous operations as the operating condition under the baseline. As such, the SSRs considered under the baseline condition may be amended to include SSRs as defined for the project condition that are applicable under the baseline condition; and
3. Site monitoring to ensure containment will be determined on a case-by-case basis due to the site-specific nature of each process. This will be based on the performance assessment of the project undertaken by the proponent. The proponent should justify the monitoring technologies used relating to the performance assessment.

If applicable, the proponent must indicate and justify why flexibility provisions have been used.

2.0 Quantification of Identified Sources, Sinks and Reservoirs

Quantification of the reductions, removals and reversals for the sources, sinks and reservoirs selected for measurement and monitoring under this protocol will be completed using the methodologies outlined in **TABLE 2.1**, below. These calculation methodologies serve to complete the following three equations for calculating the emission reductions from the comparison of the baseline and project conditions.

$$\text{Emission Reduction} = \text{Emissions}_{\text{Baseline}} - \text{Emissions}_{\text{Project}}$$

$$\begin{aligned}\text{Emissions}_{\text{Baseline}} = {} & \text{Emissions}_{\text{Fuel Extraction / Processing}} + \text{Emissions}_{\text{Capture}} + \text{Emissions}_{\text{Capture Flare}} \\ & + \text{Emissions}_{\text{Capture Vent}} + \text{Emissions}_{\text{PG Transport}} + \text{Emissions}_{\text{Process}} \\ & + \text{Emissions}_{\text{Process Flare}} + \text{Emissions}_{\text{Process Vent}}\end{aligned}$$

$$\begin{aligned}\text{Emissions}_{\text{Baseline}} = {} & \text{Emissions}_{\text{Fuel Extraction / Processing}} + \text{Emissions}_{\text{Capture}} + \text{Emissions}_{\text{Capture Flare}} \\ & + \text{Emissions}_{\text{Capture Vent}} + \text{Emissions}_{\text{PG Transport}} + \text{Emissions}_{\text{Process}} \\ & + \text{Emissions}_{\text{Process Flare}} + \text{Emissions}_{\text{Process Vent}} + \text{Emissions}_{\text{Inj Transport}} \\ & + \text{Emissions}_{\text{Injection}} + \text{Emissions}_{\text{Inj Flare}} + \text{Emissions}_{\text{Inj Vent}} \\ & + \text{Emissions}_{\text{Recirculation}}\end{aligned}$$

TABLE 2.1: Quantification Procedures

1. Project/Baseline SSR	2. Parameter / Variable	3. Unit
Project SSRs		
P1b Source Type B Gas Capture	$\text{Emissions}_{\text{Capture}} = \sum (\text{Vol. Fuel}_i * \text{EF Fuel}_{i\ CO2})\ ;\ \sum (\text{Vol. Fuel}_i * \text{EF Fuel}_{i\ CH4})\ ;\ \sum (\text{Vol. Fuel}_i * \text{EF Fuel}_{i\ N2O})$	
	$\text{Emissions}_{\text{Capture}}$	kg of CO_2 ; CH_4 ; N_2O
	Volume of Each Type of Fuel Used/ Vol. Fuel $_i$	L / m^3 / other
	CO_2 Emissions Factor for Each Type of Fuel / EF Fuel $_{I\ CO2}$	kg CO_2 per L / m^3 / other
	CH_4 Emissions Factor for Each Type of Fuel / EF Fuel $_{I\ CH4}$	kg CH_4 per L / m^3 / other
	N_20 Emissions Factor for Each Type of Fuel / EF Fuel $_{i\ N2O}$	kg N_2O per L / m^3 / other
P2b Flaring at Capture Site	$\text{Emissions}_{\text{Capture Flare}} = \sum (\text{Vol.}_{\text{Type B Gas Flared}} * \%\ CO_2 * \rho_{CO2})\ ;\ \sum (\text{Vol.}_{\text{Type B Gas Flared}} * \%\ CH_4 * \text{EF Source Type B Gas}_{CO2})\ ;\ \sum (\text{Vol.}_{\text{Source Type B Gas Flared}} * \%\ CH_4 * \text{EF Source Type B Gas}_{CH4})\ ;\ \sum (\text{Vol.}_{\text{Source Type B Gas Flared}} * \%\ CH_4 * \text{EF Source Type B Gas}_{N2O})\ ;\ \sum (\text{Vol.}_{\text{Fuel i}} * \text{EF Fuel i}_{CO2})\ ;\ \sum (\text{Vol.}_{\text{Fuel i}} * \text{EF Fuel i}_{CH4})\ ;\ \sum (\text{Vol.}_{\text{Fuel i}} * \text{EF Fuel i}_{N2O})$	
	$\text{Emissions}_{\text{Capture Flare}}$	kg of CO_2 ; CH_4 ; N_2O
	Volume of Source Type B Gas Flared / Vol. $_{\text{Type B Gas Flared}}$	m^3
	CO_2 Composition in Source Type B Gas Stream (Volumetric Basis) / % CO_2	%
	Density of CO_2/ ρ_{CO2}	kg/m^3
	Methane Composition in Source Type B Gas Stream (Volumetric Basis) / % CH_4	%
	CO_2 Emissions Factor for Source Type B Gas Flared / EF Source Type B Gas $_{CO2}$	kg CO_2 per m^3
	CH_4 Emissions Factor for Source Type B Gas Flared / EF Source Type B Gas $_{CH4}$	kg CH_4 per m^3
	N_20 Emissions Factor for Source Type B Gas Flared / EF Source Type B Gas $_{N2O}$	kg N_2O per m^3
	Volume of Each Type of Fuel Used/ Vol. Fuel $_i$	L / m^3 / other
P3b Venting at Capture Site	$\text{Emissions}_{\text{Capture Vent}} = \sum (\text{Vol.}_{\text{Source Type B Gas Vented}} * \%\ CO_2 * \rho_{CO2})\ ;\ \sum (\text{Vol.}_{\text{Source Type B Gas Vented}} * \%\ CH_4 * \rho_{CH4})$	
	$\text{Emissions}_{\text{Capture Vent}}$	kg of CO_2 ; CH_4
	Volume of Source Type B Gas Vented / Vol. $_{\text{Source Type B Gas Vented}}$	m^3
	CO_2 Composition in Source Type B Gas Stream (Volumetric Basis) / % CO_2	%
	Density of CH_4/ ρ_{CH4}	kg/m^3
P5b Source Type B Gas Transportation	$\text{Emissions}_{\text{PG Transport}} = \sum (\text{Vol. Fuel}_i * \text{EF Fuel}_{i\ CO2})\ ;\ \sum (\text{Vol. Fuel}_i * \text{EF Fuel}_{i\ CH4})\ ;\ \sum (\text{Vol. Fuel}_i * \text{EF Fuel}_{i\ N2O})$	
	$\text{Emissions}_{\text{PG Transport}}$	kg of CO_2 ; CH_4 ; N_2O
P7b Source Type B Gas Processing	$\text{Emissions}_{\text{Process}} = \sum (\text{Vol. Fuel}_i * \text{EF Fuel}_{i\ CO2})\ ;\ \sum (\text{Vol. Fuel}_i * \text{EF Fuel}_{i\ CH4})\ ;\ \sum (\text{Vol. Fuel}_i * \text{EF Fuel}_{i\ N2O})$	
	$\text{Emissions}_{\text{Process}}$	kg of CO_2 ; CH_4 ; N_2O

P8a/b Flaring at Processing Site	$Emissions_{Process\ Flare} = \sum (Vol._{Source\ Type\ B\ Gas\ Flared} * \%\ CO_2 * \rho_{CO2})\ ;\ \sum (Vol._{Source\ Type\ B\ Gas\ Flared} * \%\ CH_4 * EF\ Source\ Type\ B\ Gas_{CO2})\ ;\ \sum (Vol._{Source\ Type\ B\ Gas\ Flared} * \%\ CH_4 * EF\ Source\ Type\ B\ Gas_{CH4})\ ;\ \sum (Vol._{Source\ Type\ B\ Gas\ Flared} * \%\ CH_4 * EF\ Source\ Type\ B\ Gas_{N2O})\ ;\ \sum (Vol._{Source\ Type\ A\ Gas\ Flared} * \%\ CO_2 * \rho_{CO2})\ ;\ \sum (Vol._{Source\ Type\ A\ Gas\ Flared} * \%\ CH_4 * EF\ Source\ Type\ A\ Gas_{CO2})\ ;\ \sum (Vol._{Source\ Type\ A\ Gas\ Flared} * \%\ CH_4 * EF\ Source\ Type\ A\ Gas_{CH4})\ ;\ \sum (Vol._{Source\ Type\ A\ Gas\ Flared} * \%\ CH_4 * EF\ Source\ Type\ A\ Gas_{N2O})\ ;\ \sum (Vol._{Fuel\ i} * EF\ Fuel\ i_{CO2})\ ;\ \sum (Vol._{Fuel\ i} * EF\ Fuel\ i_{CH4});\ \sum (Vol._{Fuel\ i} * EF\ Fuel\ i_{N2O})$	
	$Emissions_{Process\ Flare}$	kg of CO_2 ; CH_4 ; N_2O
	Volume of Source Type A Gas Flared / $Vol._{Source\ Type\ A\ Gas\ Flared}$	m^3
	CO_2 Composition in Source Type A Gas Stream (Volumetric Basis) / % CO_2	%
	Methane Composition in Source Type A Gas Stream (Volumetric Basis) / % CH_4	%
	CO_2 Emissions Factor for Source Type A Gas Flared / EF Source Type A Gas_{CO2}	kg CO_2 per m^3
	CH_4 Emissions Factor for Source Type A Gas Flared / EF Source Type A Gas_{CH4}	kg CH_4 per m^3
	N_20 Emissions Factor for Source Type A Gas Flared / EF Source Type A Gas_{N2O}	kg N_2O per m^3
P9a/b Venting at Processing Site	$Emissions_{Capture\ Vent} = \sum (Vol._{Source\ Type\ B\ Gas\ Vented} * \%\ CO_2 * \rho_{CO2})\ ;\ \sum (Vol._{Source\ Type\ B\ Gas\ Vented} * \%\ CH_4 * \rho_{CH4})\ ;\ \sum (Vol._{Source\ Type\ A\ Gas\ Vented} * \%\ CO_2 * \rho_{CO2})\ ;\ \sum (Vol._{Source\ Type\ A\ Gas\ Vented} * \%\ CH_4 * \rho_{CH4})$	
	$Emissions_{Capture\ Vent}$	kg of CO_2 ; CH_4
	CO_2 Composition in Source Type A Gas (Volumetric Basis) / % CO_2	%
	Methane Composition in Source Type A Gas (Volumetric Basis) / % CH_4	%
P12 Injection Gas Transportation	$Emissions_{Inj\ Transport} = \sum (Vol.\ Fuel_i * EF\ Fuel_{i\ CO2})\ ;\ \sum (Vol.\ Fuel_i * EF\ Fuel_{i\ CH4})\ ;\ \sum (Vol.\ Fuel_i * EF\ Fuel_{i\ N2O})$	
	$Emissions_{Inj\ Transport}$	kg of CO_2 ; CH_4 ; N_2O
P14 Injection Unit Operation	$Emissions_{Injection} = \sum (Vol.\ Fuel_i * EF\ Fuel_{i\ CO2})\ ;\ \sum (Vol.\ Fuel_i * EF\ Fuel_{i\ CH4})\ ;\ \sum (Vol.\ Fuel_i * EF\ Fuel_{i\ N2O})$	
	$Emissions_{Injection}$	kg of CO_2 ; CH_4 ; N_2O
P15 Flaring at Injection Site	$Emissions_{Inj\ Flare} = \sum (Vol._{Injection\ Gas\ Flared} * \%\ CO_2 * \rho_{CO2})\ ;\ \sum (Vol._{Injection\ Gas\ Flared} * \%\ CH_4 * EF\ Injection\ Gas_{CO2})\ ;\ \sum (Vol._{Injection\ Gas\ Flared} * \%\ CH_4 * EF\ Injection\ Gas_{CH4})\ ;\ \sum (Vol._{Injection\ Gas\ Flared} * \%\ CH_4 * EF\ Injection\ Gas_{N2O})\ ;\ \sum (Vol._{Fuel\ i} * EF\ Fuel\ i_{CO2})\ ;\ \sum (Vol._{Fuel\ i} * EF\ Fuel\ i_{CH4})\ ;\ \sum (Vol._{Fuel\ i} * EF\ Fuel\ i_{N2O})$	
	$Emissions_{Inj\ Flare}$	kg of CO_2 ; CH_4 ; N_2O
	Volume of Injection Gas Flared / $Vol._{Injection\ Gas\ Flared}$	m^3
	CO_2 Composition in Injection Gas Stream (Volumetric Basis) / % CO_2	%
	Methane Composition in Injection Gas Stream (Volumetric Basis) / % CH_4	%
	CO_2 Emissions Factor for Injection Gas Flared / EF Injection Gas_{CO2}	kg CO_2 per m^3
	CH_4 Emissions Factor for Injection Gas Flared / EF Injection Gas_{CH4}	kg CH_4 per m^3
	N_20 Emissions Factor for Injection Gas Flared / EF Injection Gas_{N2O}	kg N_2O per m^3
P16 Venting at Injection Site	$Emissions_{Inj\ Vent} = \sum (Vol._{Injection\ Gas\ Vented} * \%\ CO_2 * \rho_{CO2})\ ;\ \sum (Vol._{Injection\ Gas\ Vented} * \%\ CH_4 * \rho_{CH4})$	
	$Emissions_{Inj\ Vent}$	kg of CO_2 ; CH_4
	Volume of Injection Gas Vented / $Vol._{Injection\ Gas\ Vented}$	m^3

P19 Recycled Injection Gas	$Emissions_{Recirculation} = \sum (Vol._{Injected\ Gas\ Recycled} * \%\ CO_2 * \rho_{CO})$	
	$Emissions_{Recirculation}$	kg of CO_2 ; CH_4
	Volume of Injected Gas Produced at Adjacent Locations / $Vol._{Injected\ Gas\ Recycled}$	m^3
P21 Fuel Extraction and Processing	$Emissions_{Fuel\ Extraction\ /\ Processing} = \sum (Vol.\ Fuel_i * EF\ Fuel_{i\ CO2})$; $\sum (Vol.\ Fuel_i * EF\ Fuel_{i\ CH4})$; $\sum (Vol.\ Fuel_i * EF\ Fuel_{i\ N2O})$	
	$Emissions_{Fuel\ Extraction\ /\ Processing}$	kg of CO2e
	Volume of Fossil Fuel Combusted for P1, P2, P5, P7, P8, P12, P14 and P15 / Vol. Fuel	L/ m^3/ Other
	CO_2 Emissions Factor for Fuel Including Production and Processing / $EF\ Fuel_{CO2}$	kg CO_2 per L / m^3 / other
	CH_4 Emissions Factor for Fuel Including Production and Processing / $EF\ Fuel_{CH4}$	kg CH_4 per L / m^3 / other
	N_20 Emissions Factor for Fuel Including Production and Processing / $EF\ Fuel_{N2O}$	kg N_2O per L / m^3 / other
Baseline SSRs		
B1b Source Type B Gas Capture	$Emissions_{Capture} = \sum (Vol.\ Fuel_i * EF\ Fuel_{i\ CO2})$; $\sum (Vol.\ Fuel_i * EF\ Fuel_{i\ CH4})$; $\sum (Vol.\ Fuel_i * EF\ Fuel_{i\ N2O})$	
	$Emissions_{Capture}$	kg of CO_2 ; CH_4 ; N_2O
B2b Flaring at Capture Site	$Emissions_{Capture\ Flare} = \sum (Vol._{Source\ Type\ B\ Gas\ Flared} * \%\ CO_2 * \rho_{CO2})$; $\sum (Vol._{Source\ Type\ B\ Gas\ Flared} * \%\ CH_4 * EF\ Source\ Type\ B\ Gas_{CO2})$; $\sum (Vol._{Source\ Type\ B\ Gas\ Flared} * \%\ CH_4 * EF\ Source\ Type\ B\ Gas_{CH4})$; $\sum (Vol._{Source\ Type\ B\ Gas\ Flared} * \%\ CH_4 * EF\ Source\ Type\ B\ Gas_{N2O})$; $\sum (Vol._{Fuel\ i} * EF\ Fuel\ i_{CO2})$; $\sum (Vol._{Fuel\ i} * EF\ Fuel\ i_{CH4})$; $\sum (Vol._{Fuel\ i} * EF\ Fuel\ i_{N2O})$	
	$Emissions_{Capture\ Flare}$	kg of CO_2 ; CH_4 ; N_2O
B3b Venting at Capture Site	$Emissions_{Capture\ Vent} = \sum (Vol._{Source\ Type\ B\ Gas\ Vented} * \%\ CO_2 * \rho_{CO2})$; $\sum (Vol._{Source\ Type\ B\ Gas\ Vented} * \%\ CH_4 * \rho_{CH4})$	
	$Emissions_{Capture\ Vent}$	kg of CO_2 ; CH_4
B8 Flaring at Processing Site	$Emissions_{Source\ Type\ B\ Flare} = \sum (Vol._{Source\ Type\ A\ Gas\ Flared} * \%\ CO_2 * \rho_{CO2})$; $\sum (Vol._{Source\ Type\ A\ Gas\ Flared} * \%\ CH_4 * EF\ Source\ Type\ A\ Gas_{CO2})$; $\sum (Vol._{Source\ Type\ A\ Gas\ Flared} * \%\ CH_4 * EF\ Source\ Type\ A\ Gas_{CH4})$; $\sum (Vol._{Source\ Type\ A\ Gas\ Flared} * \%\ CH_4 * EF\ Source\ Type\ A\ Gas_{N2O})$; $\sum (Vol._{Fuel\ i} * EF\ Fuel\ i_{CO2})$; $\sum (Vol._{Fuel\ i} * EF\ Fuel\ i_{CH4})$; $\sum (Vol._{Fuel\ i} * EF\ Fuel\ i_{N2O})$	
	$Emissions_{Source\ Type\ B\ Flare}$	kg of CO_2 ; CH_4 ; N_2O
B9 Venting at Processing Site	$Emissions_{Capture\ Vent} = \sum (Vol._{Source\ Type\ B\ Gas\ Vented} * \%\ CO_2 * \rho_{CO2})$; $\sum (Vol._{Source\ Type\ B\ Gas\ Vented} * \%\ CH_4 * \rho_{CH4})$; $\sum (Vol._{Source\ Type\ A\ Gas\ Vented} * \%\ CO_2 * \rho_{CO2})$; $\sum (Vol._{Source\ Type\ A\ Gas\ Vented} * \%\ CH_4 * \rho_{CH4})$	
	$Emissions_{Capture\ Vent}$	kg of CO_2 ; CH_4
B13 Fuel Extraction and Processing	$Emissions_{Fuel\ Extraction\ /\ Processing} = \sum (Vol.\ Fuel_i * EF\ Fuel_{i\ CO2})$; $\sum (Vol.\ Fuel_i * EF\ Fuel_{i\ CH4})$; $\sum (Vol.\ Fuel_i * EF\ Fuel_{i\ N2O})$	
	$Emissions_{Fuel\ Extraction\ /\ Processing}$	kg of CO2e

APPENDIX A: Glossary of New Terms

Enhanced Oil Recovery:	Oil recovery superior to what is obtained using the natural pressure of the reservoir. For the purposes of this protocol, this is obtained through carbon dioxide and/or acid gas injection.
Capture Site:	The point in the process where gas containing GHGs that would otherwise be vented or flared is captured for eventual injection as part of an EOR project.
Leakage:	Escape of the injected gas into adjacent wells or underground formations.
Migration:	Lateral movement of the injected gas within the reservoir.
Seepage:	Escape of the injected gas to the biosphere, including potable water and atmospheric environment.