Intentions Paper: Carbon Capture and Storage

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Acronyms

ANAB: ANSI National Accreditation Body

B.C.: British Columbia

B.C. LCFB: British Columbia Low Carbon Fuels Branch

CARB: California Air Resources Board

CFR: Clean Fuel Regulation

CI: Carbon Intensity

ECCC: Environment and Climate Change Canada

EF: Emission Factor

EOR: Enhanced oil recovery

GHG: Greenhouse Gas

GWP: Global warming potential

IPCC: The Intergovernmental Panel on Climate Change

LCFS: British Columbia Low Carbon Fuel Standard

LCFA: (B.C.) Low Carbon Fuels Act

LFO: Linear facility operations

MECS: (B.C.) Ministry of Energy and Climate Solutions

SCC: Standards Council of Canada

SSR: Sources, sinks, and reservoirs

1 Introduction

British Columbia's Low Carbon Fuel Standard (LCFS) incorporates the lifecycle assessment (LCA) of the Carbon Intensity (CI) of low carbon fuels supplied in the Province. This intentions paper proposes requirements for fuel producers who would like to include carbon capture and storage (CCS) and carbon capture, utilization and storage (CCUS) in the CI applications they submit to the Province for approval under the *Low Carbon Fuels Act*. The document covers eligibility criteria, lifecycle modeling considerations, monitoring, measurement protocols, and risk assurance mechanisms.

- **Scope:** Eligibility criteria, lifecycle modelling considerations, monitoring and measurement requirements, risk assurance mechanisms and required documentation.
- **Next steps:** Following public consultation, this document may be used to inform regulation updates as required and be supported further by an information bulletin.
- **Implementation timeline:** Legislative amendments may be proposed for the earliest legislative session possible.
- **Transparency:** Stakeholders will receive ample notice regarding the finalized requirements in advance of implementation.

Clarification (2025-01-16): This Intentions Paper describes a refinement to the lifecycle assessment methodology for alternative fuels, so that producers applying for B.C. low carbon fuel codes can better incorporate CCS into their production processes and carbon intensity applications. Under the *Low Carbon Fuels Act*, the carbon intensities of the fossil-derived component of base fuels are prescribed in the Low Carbon Fuels (Technical) Regulation. This paper does not express an intention to change these values.

The main changes the Ministry plans to implement include:

1. The clarification of boundary conditions used in lifecycle assessment modelling and quantification of emission sources, sinks, and reservoirs that must be included.
2. The addition of a discount factor to account for long term risk of leakage/reversal.
3. The addition of an annual sequestration project report, consisting of two sections, volumetric CO_2 reporting, and risk identification and mitigation.

The Ministry is accepting feedback on these changes. Responses must be in writing and must be submitted by email or mail before 7 a.m. on February 13, 2025, to one of the following addresses:

Email: lcfs@gov.bc.ca

Mail: Low Carbon Fuels Branch
B.C. Ministry of Energy and Climate Solutions
P.O. Box 9314 Stn Prov Govt
Victoria, B.C. V8W 9N1

This intentions paper has been posted online on the Ministry's website for comment at: https://gov.bc.ca/lowcarbonfuels.

1.1 Carbon Capture (Utilization) and Storage

CCS is a method used to capture carbon dioxide (CO_2) emissions from an industrial source, and permanently store them in geologic formations or repurpose them for various applications. CCS can be used to lower the CI of a fuel by applying a negative emission credit to the lifecycle emissions. Captured CO_2 can be used for dedicated carbon capture and storage (CCS); utilized in some manner, known as carbon capture and utilization (CCU); or some combination of both, known as carbon capture utilization and storage (CCUS).

The most common form of CCUS is enhanced oil recovery (EOR). EOR is the process of injecting CO_2 into an oil reservoir with the goal of enhancing the oil extraction process. In the process, a large portion of the CO_2, approximately one third of the quantity injected, remains in the reservoir, and the remaining two-thirds come out with the extracted oil. The CO_2 that comes out with the extracted oil is typically recycled/recaptured, with only small sources of leakages in the system before being reinjected. Operators continue to recycle/reinject the CO_2 until effectively all the CO_2 initially injected has been sequestered.

The details pertaining to both CCS and CCUS are discussed in this paper. Dedicated sequestration activities injecting CO_2 into depleted oil and gas reservoirs, saline reservoirs, and mafic/ultra mafic formations will use the term CCS throughout. Any injection being used for enhanced oil recovery will use the term EOR.

2 Eligibility/Criteria

CCS projects are eligible to be included as an emission reduction in carbon intensity modelling. Projects may include dedicated storage in geologic formations, or CCUS projects, including EOR projects. Projects that must decrease reservoir pressure after the end of injection are not eligible under the B.C. LCFS.

Projects must account for all direct and indirect emissions of the process. This includes upstream emissions, plant emissions, and downstream emissions. The boundary conditions, and sources, sinks, and reservoirs (SSRs) are defined in section 6 below.

Projects must undergo third party verification as per the requirements set out by the B.C. LCFS.

Project owners must have uncontested ownership over the pore space where CO_2 is injected and sequestered. Project proponents must demonstrate compliance with relevant local, provincial, and federal regulations regarding land use and consultation, including with First Nations as applicable.

For projects to be eligible, the emissions reductions must meet the following criteria:

1. They must be real, demonstrable and quantifiable.
2. They must be verifiable through third-party oversight.
3. The project owner must have clear ownership of the emissions and storage rights.
4. Emissions reductions must be counted once under the B.C. LCFS, ensuring no double-counting with other programs.

3 Project Periods

The project can be defined by different stages within its lifecycle. In each stage of its lifecycle, specific requirements are in place. These periods include the credit period, and stabilization period.

3.1 Fuel Code Eligibility Period

Fuel production projects are eligible to apply for approval of fuel codes using CCS/CCUS for the entirety of the injection phase. The fuel code eligibility period begins on the day of the first injection and ends once all project-related injections have taken place. It then transitions into the stabilization period.

At the outset of the fuel code eligibility period, an annual sequestration project report must be submitted as per subsection 8.1.1. This annual reporting should continue to be updated throughout the fuel code eligibility period as new information arises. During the fuel code eligibility period, project reports must be submitted annually. The Annual Sequestration Report must include:

1. Volumetric CO_2 measurements,
2. Risk assessment and mitigation strategies,
3. Any changes in project operations from the previous year.

This report must be submitted annually and verified according to the future regulations of the Ministry and the templates that will be provided.

3.2 Stabilization Period

Once the injection is complete, the project then transitions into the stabilization period. Fuel producers are required to continue obtaining information from the injection entity to ensure permanence in line with the requirements in this intentions paper and any following legislation. During the stabilization period, verified annual sequestration project reports must continue to be submitted. The stabilization period begins the day that the last injection takes place and continues until the following conditions are met:

1. A verified statement of permanence is submitted, issued by the appropriate regional authority, confirming that CO_2 storage is secure.
2. A sequestration project report indicates the project's risk level is classified as low or medium.

The Stabilization Period ends once these documents are submitted to and accepted by the Ministry, ensuring that the CO_2 is permanently stored. If any risks of leakage or instability are identified during this period, further monitoring and reporting may be required. A discount factor is applied as discussed in subsection 4.1, which assumes a conservative estimate of emissions are leaked for all projects. The director may reassess and adjust compliance units at a future date if leakage occurs.

4 Risk Assurance

To ensure the permanence of CO_2 storage, the Ministry intends to implement some safeguards. This includes applying a discount factor to account for potential leakages, rules surrounding double counting of emissions, and third-party verification. In addition, the Ministry intends to preapprove and publish certain regions where the stringency of legislation in place governing CCS aligns with the B.C. LCFS, ensuring that CO_2 storage is permanent.

The Ministry reserves the right to decline projects in regions where it cannot be demonstrated that regulations are stringent enough to ensure permanent storage. This includes, but is not limited to requirements for site characterization, well construction and operation, injection monitoring, and well abandonment.

It is expected and required that plans are in place that any CO_2 extracted from the oil from the reservoir is reinjected into the same EOR scheme for permanent storage. As previously mentioned, projects that must decrease reservoir pressure after the end of the injection are not eligible under the B.C. LCFS.

The Ministry intends to require project proponents to submit an annual sequestration project report, described in subsection 8.1.1. Upon project completion, project proponents would then provide a verified statement of permanence as required by the regulator in the local jurisdiction and a verified sequestration project report. Once the Ministry approves these two documents, a statement of permanence will be issued.

4.1 Discount Factor

To account for unintentional releases of CO_2 after or during the injection period that are unmeasurable, the Ministry intends to apply a discount factor, essentially withholding a certain number of emissions indefinitely. The discounted emissions are subtracted from the negative emission credit a fuel producer would receive towards their CI. These emission credits are assumed to be retired immediately and can never be recouped by the fuel producer. This is intended to cover the project's entire lifespan and beyond and address the risk of CO_2 leakage, though this is expected to be low. The director can reassess and adjust the number of compliance units added or subtracted from the balance of the person, including adjustments to below zero as per section 32 of the Low Carbon Fuels Act (LCFA).

A discount factor will be applied to baseline emissions, i.e. the injected quantity of CO_2. These emissions are assumed to be emitted to the atmosphere and are therefore never able to be claimed back. It is proposed to apply a discount factor (D) of 0.005, consistent with the CFR, and AB TIER programs.

The quantity of discounted emissions, $X_{discount}$ is calculated as per Equation 1.

$$X_{discount} = X_{injected} * D \quad \text{Equation 1}$$

Here $X_{injected}$ is the measured quantity of CO_2 directly upstream of the point of injection detailed in Equation 5, and D is the discount factor value of 0.005.

With each CI application, the quantity of discounted emissions is applied to the sequestration percentage, Equation 3, as discussed in section 7 below

4.2 Double Counting

Carbon sequestration poses a risk of double counting when emissions reductions are reported across multiple greenhouse gas (GHG) programs. Fuel producers employing sequestration achieve a lower carbon intensity (CI), which generates emissions reductions when the fuel is supplied. To prevent duplicate claims for the same reductions in different GHG inventories, the Ministry proposes the following safeguards:

1. Statutory Declaration Requirement:
   Project proponents must submit a statutory declaration affirming that the emissions reductions included in their CI applications are not reported under any other GHG inventory. This requirement applies to both compliance-based and voluntary markets.

2. Multi-Program Reporting Exception:
   Fuel producers participating in multiple clean fuels programs, where carbon capture and storage (CCS) is used to reduce CI, may receive approved CI values under multiple programs. In such cases, producers must:
   - Report fuel volumes associated with each fuel code separately.
   - Declare the specific amount of sequestration credits claimed under other clean fuels programs, including but not limited to the ECCC Clean Fuel Regulation (CFR), California LCFS, Oregon Clean Fuels Program (CFP), and Washington Clean Fuels Standard (CFS).
3. Distinct yet Stackable Programs:
   The B.C. LCFS and ECCC CFR programs are distinct but stackable. Fuel supplied in B.C. using CCS/CCUS technologies must be reported under both programs, ensuring transparency and proper accounting.

The Ministry seeks feedback on this approach to ensure that sequestration credits are accurately reported and only counted once across all applicable and non-stackable programs.

5 Project Description

This section outlines both the baseline and project case conditions. The baseline represents what would occur in the absence of the capture project. The difference in emissions between the baseline and the project emissions, less any discount factors is the value entered into the GHGenius model as the sequestration fraction as discussed in section 7 below.

5.1 Baseline Condition

The baseline condition is defined in accordance with ISO 14064-2 section 3.2.6 as a "hypothetical reference case that best represents the conditions most likely to occur in the absence of a proposed GHG project". The baseline condition is a fuel production facility with no carbon capture equipment installed and CO_2 is assumed to be vented to the atmosphere.

The baseline for this protocol is dynamic projection based. Therefore, during the project, the total quantity of CO_2 measured directly upstream of the injection wellheads is the baseline condition. Any recycled and reinjected CO_2 must not be included in this quantity. Measuring CO_2 at this location avoids the need to quantify upstream emissions, including any vented and fugitive emissions that occur during the capture, compression/dehydration, and transport. This is because these emissions will occur under both the baseline and project scenarios.

In addition to the six principles that must be upheld under ISO 14064-2, four additional parameters are important for consideration when determining a baseline including:

- Functional equivalence: The baseline and project scenarios must produce the same quantity of energy (measured in megajoules) at the facility.
- Additionality: Emission reductions must be unique to the project and cannot be credited under any other program.
- Leakage: Any indirect changes in emissions resulting from the project (e.g., shifts in market or activity) must be accounted for.
- Permanence: The risk of CO_2 leakage is mitigated through appropriate site selection, continuous monitoring, verification, and a risk assurance discount factor

5.2 Project Condition

The project condition describes the operational setup in which carbon capture equipment is integrated into the fuel production process. The entity can receive an avoided emissions credit for the quantity of carbon captured, less the emissions that occur because of the capture, transport, and injection. Upstream and downstream emissions must be included in the final sequestration percentage.

The process flow diagrams (PFD) for CCS and EOR are shown below in Figure 1 and Figure 2 respectively with the system boundary for sequestration marked by a dashed line. The injection meter is shown as a green dot in both figures.

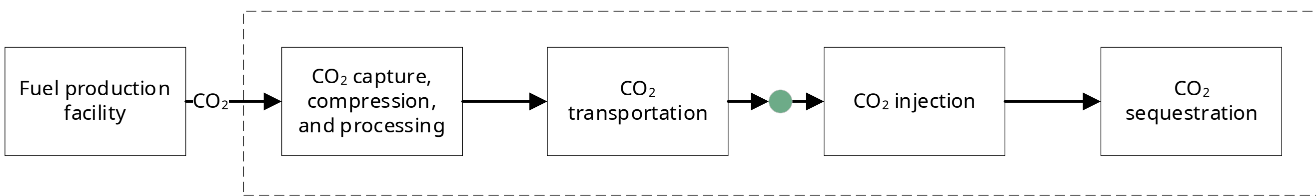

Figure 1: Project case – CCS- PFD

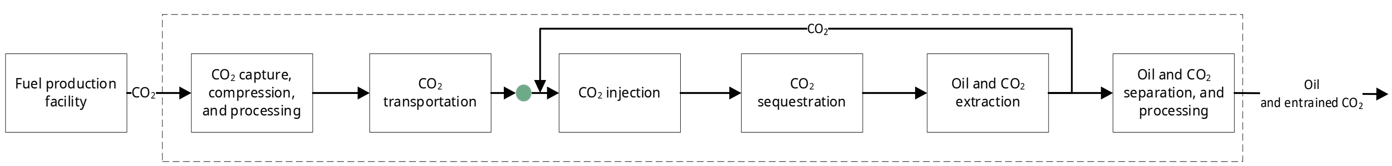

Figure 2: Project case – EOR- PFD

5.3 Project Entities

CCS and EOR projects often involve multiple entities working together across different stages of the project from capture to injection and subsequent permanent storage of CO_2. Each entity must collaborate to provide the necessary data for LCA to the fuel producer. The fuel producer who applies for a fuel code is required to obtain and submit all the upstream and downstream emission information as outlined in this document.

5.3.1 Capture Entity

The capture entity is typically the fuel producer; however, carbon capture equipment may be outsourced to an external entity. It is expected that the entity submitting the carbon intensity application will collect all relevant data from the capture entity and will include it in the LCA modelling.

5.3.2 Transport Entity

The transport entity may be the fuel producer or a third party. The fuel producer who submits the application is responsible for obtaining and submitting all information regarding the emissions during transportation, including emissions from pipelines, vehicles or other transport methods.

5.3.3 Injection/Sequestration Entity

In some cases, CO_2 is sold to another entity for utilization, while in other cases the fuel producer pays for the sequestration. In either case, the fuel producer is responsible for obtaining and submitting emissions information regarding injections, and any CO_2 re-injection/recycling that occurs.

5.3.4 Oil Extraction Entity

In cases where the CO_2 is sold and utilized for enhanced oil recovery, either by the fuel producer, or another entity, the fuel producer must work with the entity responsible for oil extraction to obtain emissions information.

6 Sources, Sinks and Reservoirs

The following sources, sinks, and reservoirs (SSR) are identified as potential contributors to the overall emissions in a carbon sequestration project. Due to impracticality of including every single emission source, the Ministry proposes a targeted approach based on factors such as data availability, magnitude of effect, and a realistic balance of effort and accuracy. The tables indicate whether each emissions source is included or excluded within the methodology. Where possible, the Ministry intends to align with Environment and Climate Change Canada's (ECCC) Clean Fuels Regulation (CFR).

Emissions are accounted for across the lifecycle stages of the project, including project setup/drilling, decommissioning, capture, compression/dehydration, transportation, and injection. For EOR, production and recycling must also be included.

The SSRs associated with each stage of the process for CCS and EOR are shown in Figure 3 and Figure 4 respectively.

In subsequent sections of this document, only SSRs will be discussed further. Section 7 below.

6.1.1 Baseline

The Ministry intends to use a dynamic baseline, using measured CO_2 directly before injection. By setting the baseline directly upstream of the injection site, the fugitive and vented emissions that arise from capture, compression and dehydration, and transport are effectively accounted for. Thus, SSR's P10-P15 do not need to be quantified.

Table 1: Baseline included SSRs

Included Emissions		
SSR	**Lifecycle stage**	**Description**
B1-Injected CO_2	On-site during operation	Quantity of CO_2 injected into the sequestration site. This baseline must be measured directly upstream, as close as possible to the point of injection. Excludes re-injected fluid.
Excluded Emissions		
SSR	**Lifecycle stage**	**Description**
B2- Injected CH_4	On-site during operation	Quantity of CH_4 injected into the sequestration site. This baseline is measured directly upstream, as close as possible to the point of injection. Excludes re-injected fluid.
B3- Injected N_2O	On-site during operation	Quantity of N_2O injected into the sequestration site. This baseline is measured directly upstream, as close as possible to the point of injection. Excludes re-injected fluid.

6.1.2 Dedicated Storage Project SSR

The SSR's for CCS projects is shown in Table 2 below and detailed in Figure 3 of Appendix A- .

Table 2: Dedicated storage project SSRs

Included Emissions		
SSR	**Lifecycle stage**	**Description**
$P3_{CCS}$- Construction of carbon capture facility and well drilling	Onsite- Before Project	Construction of CCS facilities and well drill service. Emissions will need to be quantified in the case of a potential kick or blowout event that could release hydrocarbons during the drilling of injection and monitoring wells.
$P4_{CCS}$- Production and delivery of capture materials	Upstream-during project	Material inputs, including specialized chemicals or additives such as amine sorbents, are required for CO_2 capture and processing. Greenhouse gas emissions are attributed to the fossil fuel consumption for transport of these materials, and the electricity and fossil fuel inputs for their production.

$P6_{CCS}$- Off-site electricity generation	Upstream- during project	Emissions associated with the off-site generation of electricity that is consumed at project facilities. Included in sequestration energy inputs and uses a default grid mix for the area.
$P7_{EOR}$- Off-site heat generation	Upstream-during project	Emissions associated with the off-site generation of heat that is consumed at project facilities. Included in sequestration energy inputs.
$P8_{CCS}$-Onsite electricity generation	Onsite-during project	Electricity inputs may be required for CO_2 capture, compression, transportation and injection. Electricity may be generated independently or from cogeneration within the project boundary. The quantity and type of fuels consumed to generate electricity, and the quantity of electricity consumed by the project from each generating source would be tracked. Included in sequestration energy inputs, and user defined grid mix may be modified to account for onsite generation method.
$P9_{CCS}$- Fuel consumption	Onsite-during project	Fuel use may be required for CO_2 capture, processing, compression, dehydration, transportation and injection or for heat or electricity generation. The quantity and type of fuels consumed from each source would be tracked. Included in sequestration energy inputs. Emissions calculated elsewhere in the model
$P16_{CCS}$- Venting at injection sites	Onsite-during project	Planned and emergency CO_2 venting may be necessary for injection well work overs, mechanical integrity checks, and maintenance. Instances of venting must be logged, including the duration of the venting event and the estimated quantities and makeup of gasses vented.
$P17_{CCS}$- Fugitive emissions at injection sites	Onsite-during project	Unintended or unplanned leaks of gas at the CO_2 injection well sites may occur through valves, flanges, pipe connections, mechanical seals, or related equipment.
$P18_{CCS}$- Subsurface to atmosphere emissions	Onsite-during project	Unintentional atmospheric emissions can happen due to gas migrating through unnoticed faults, fractures, or subsurface equipment caused by damaged casing,

		cement, wellhead, packer, or tubing. CO_2 that escapes from the designated storage area but stays underground is treated the same as if it had leaked into the atmosphere and must be measured accordingly. This also includes deliberate releases, removals, transfers of CO_2, or net reversals.
$P19_{CCS}$- Loss, Disposal, or Recycling of Materials Used in CO_2 Capture Processes	Downstream- During project	Material inputs are either disposed of or recycled at the end of their useful life. Greenhouse gas emissions result from the transportation of materials to industrial landfill and/or material recycling processes. Emissions are also associated with the loss of material during project operation.
Excluded Emissions		
SSR	**Lifecycle stage**	**Description**
$P1_{CCS}$- CCS construction material	Upstream- Before Project	Production and delivery of materials used for the construction of capture, transport, and CCS facilities. Materials such as steel and concrete will need to be delivered to the site.
$P2_{CCS}$- CCS construction and emissions due to land clearing	Onsite- Before project	Land clearance and soil carbon loss from construction of CCS facilities.
$P5_{CCS}$- Fuel extraction, processing, and delivery	Onsite- Before project	Fuels used throughout the process require extraction, processing and transport to site. Emissions are accounted for elsewhere in GHGenius.
$P10_{CCS}$- Venting at capture site	Onsite- during project	Venting occurs during the capture process. May be also be a result of equipment maintenance or emergency shutdowns. Already accounted for by using a baseline of measured CO_2 at injection site.
$P11_{CCS}$- Fugitive emissions at capture site	Onsite- during project	Unintended leaks of gas from the CO_2 capture and processing unit may occur through faulty seals, loose fittings, or equipment. Accounted for by using a baseline of measured CO_2 at injection site.
$P12_{CCS}$- Venting during compression/dehydration	Onsite- during project	Planned and emergency CO_2 venting may be necessary for compressor and dehydrator maintenance and/or emergency shutdowns. Accounted for by using a baseline of measured CO_2 at injection site.

P13$_{CCS}$- Fugitive emissions during compression/dehydration	Onsite- during project	Unintended leaks of gas from the compressor and/or dehydrator may occur through seals, loose fittings, equipment, or compressor packing. These gases will be composed primarily of CO_2 with trace amounts of other gases.
P14$_{CCS}$- Venting emissions during transport	Onsite- during project	Planned and emergency CO_2 venting may be necessary for pipeline maintenance and/or shutdowns.
P15$_{CCS}$- Fugitive emissions during transport	Onsite- during project	Unintended leaks of gas from the CO_2 pipeline, transportation equipment, and additional compressors may occur through seals, loose fittings, equipment, or compressor packing. These gases will be composed primarily of CO_2 with trace amounts of other gases.
P20$_{CCS}$- Decommissioning of carbon capture, and storage facilities.	Downstream- After project	Infrastructure is decommissioned at the end of project operations. This involves the disassembly of the equipment, demolition of on-site structures, landfill disposal of some materials, environmental restoration, re-grading, planting or seeding, and transportation of materials off-site. Greenhouse gas emissions result from fossil fuels combustion and electricity use.

6.1.3 EOR Project SSR

The SSRs relevant to the project condition are shown in in Table 3 below and detailed in Figure 4 of Appendix A-

Table 3: EOR project SSRs

Included Emissions		
SSR	**Lifecycle stage**	**Description**
P3$_{EOR}$- Construction of carbon capture facility and well drilling	Onsite- Before Project	Construction of CCS facilities and well drill service. Emissions will need to be quantified in the case of from the potential kick or blowout event that could release hydrocarbons during the drilling of injection and monitoring wells.
P4$_{EOR}$- Production and delivery of capture materials	Upstream-during project	Material inputs, including specialized chemicals or additives such as amine sorbents, are required for CO_2 capture and processing. Greenhouse gas emissions are attributed to the fossil fuel consumption

		for transport of these materials, and the electricity and fossil fuel inputs for their production.
P6$_{EOR}$- Off-site electricity generation	Upstream- during project	Emissions associated with the off-site generation of electricity that is consumed at project facilities. Included in sequestration energy inputs and uses a default grid mix for the area.
P7$_{EOR}$- Off-site heat generation	Upstream-during project	Emissions associated with the off-site generation of heat that is consumed at project facilities. Included in sequestration energy inputs.
P8$_{EOR}$-Onsite electricity generation	Onsite-during project	Electricity inputs may be required for CO_2 capture, compression, transportation and injection, and re-injection. Electricity may be generated independently or from cogeneration within the project boundary. The quantity and type of fuels consumed to generate electricity, and the quantity of electricity consumed by the project from each generating source would be tracked. Included in sequestration energy inputs, and user defined grid mix may be modified to account for onsite generation method.
P9$_{EOR}$- Fuel consumption	Onsite-during project	Fuel use may be required for CO_2 capture, processing, compression, dehydration, transportation, injection, and re-injection or for heat or electricity generation. The quantity and type of fuels consumed from each source would be tracked. Included in sequestration energy inputs. Emissions calculated elsewhere in the model
P16$_{EOR}$- Venting at injection sites, production/extraction, and recycling streams	Onsite-during project	Planned and emergency CO_2 venting may be necessary for injection well work overs, mechanical integrity checks, and maintenance. Instances of venting must be logged, including the duration of the venting event and the estimated quantities and makeup of gasses vented.
P17$_{EOR}$- Fugitive emissions at injection sites, production/extraction, and recycling streams	Onsite-during project	Unintended or unplanned leaks of gas at the CO_2 injection well sites may occur through valves, flanges, pipe connections, mechanical seals, or related equipment.

P18$_{EOR}$- Subsurface to atmosphere emissions	Onsite-during project	Unintentional atmospheric emissions can happen due to gas migrating through unnoticed faults, fractures, or subsurface equipment caused by damaged casing, cement, wellhead, packer, or tubing. CO_2 that escapes from the designated storage area but stays underground is treated the same as if it had leaked into the atmosphere and must be measured accordingly. This also includes deliberate releases, removals, transfers of CO_2, or net reversals.
P19$_{EOR}$- Emissions from flaring at injection, production, and CO_2 recycling stream	On site- during project	Planned and emergency flaring may be necessary for injection or production well sites or during work overs, mechanical integrity checks, re-injection stream flaring, these flare volumes and subsequent emissions are additional to baseline scenario flaring due to EOR scheme oil production. Instances of project flaring is logged, including the duration of the flaring event, and sources of gases flared include any additional natural gas and the estimated quantities flared.
P20$_{EOR}$- Loss, disposal, and recycling of materials used in CO_2 capture process	Downstream- during project	Material inputs are either disposed of or recycled at the end of their useful life. Greenhouse gas emissions result from the transportation of materials to industrial landfill and/or material recycling processes. Emissions are also associated with the loss of material during project operation.)
P22$_{EOR}$- Entrained CO_2	Onsite- During project	Any emissions entrained within products sold/transferred outside of product boundary. This may include CO_2 entrained in produced water, natural gas, and crude oil. This can be excluded if it is reinjected into the same formation.
P23$_{EOR}$ - Transferred CO_2	Onsite- During project	Any CO_2 that has been measured at injection meter, but not reinjected and is transferred outside of project boundary. Entities are expected to re-inject any extracted emissions at the end of the useful life of the reservoir.
Excluded Emissions		
SSR	**Lifecycle stage**	**Description**

$P1_{EOR}$- CCS construction material	Upstream- Before Project	Production and delivery of materials used for the construction of capture, transport, and CCS facilities. Materials such as steel and concrete will need to be delivered to the site.
$P2_{EOR}$- Land clearing and soil carbon loss from construction of EOR facilities	Onsite- Before project	Land clearance and soil carbon loss from construction of EOR facilities
$P5_{EOR}$- Fuel extraction, processing, and delivery	Onsite- Before project	Fuels used throughout the process require extraction, processing and transport to site. Emissions are accounted for elsewhere in GHGenius.
$P10_{EOR}$- Venting at capture site	Onsite- during project	Venting occurs during the capture process. May be also be a result of equipment maintenance or emergency shutdowns. Already accounted for by using a baseline of measured CO_2 at injection site.
$P11_{EOR}$- Fugitive emissions at capture site	Onsite- during project	Unintended leaks of gas from the CO_2 capture and processing unit may occur through faulty seals, loose fittings, or equipment. Accounted for by using a baseline of measured CO_2 at injection site.
$P12_{EOR}$- Venting during compression/dehydration	Onsite- during project	Planned and emergency CO_2 venting may be necessary for compressor and dehydrator maintenance and/or emergency shutdowns. Accounted for by using a baseline of measured CO_2 at injection site.
$P13_{EOR}$- Fugitive emissions during compression/dehydration	Onsite- during project	Unintended leaks of gas from the compressor and/or dehydrator may occur through seals, loose fittings, equipment, or compressor packing. These gases will be composed primarily of CO_2 with trace amounts of other gases.
$P14_{EOR}$- Venting during transport	Onsite- during project	Planned and emergency CO_2 venting may be necessary for pipeline maintenance and/or shutdowns.
$P15_{EOR}$- Fugitive during transport	Onsite- during project	Unintended leaks of gas from the CO_2 pipeline, transportation equipment, and additional compressors may occur through seals, loose fittings, equipment, or compressor packing. These gases will be composed primarily of CO_2 with trace amounts of other gases.

$P21_{EOR}$- Decommissioning of carbon capture, and EOR facilities.	Downstream- After project	Infrastructure is decommissioned at the end of project operations. This involves the disassembly of the equipment, demolition of on-site structures, landfill disposal of some materials, environmental restoration, re-grading, planting or seeding, and transportation of materials off-site. Greenhouse gas emissions result from fossil fuels combustion and electricity use.

7 Quantification and LCA Modelling

In this section, the equations to calculate inputs to the model are outlined, and in Appendix B- , each variable is quantified and identified whether measurement or estimation is required.

Currently, GHGenius models captured CO_2 as a waste and assigns a negative emission credit applied to the fuel production emissions. This reflects the avoidance of emitting CO_2 into the atmosphere, whether it is permanently sequestered or used for enhanced oil recovery. In the current model, both methods are considered to provide permanent storage. The B.C. LCFS proposes to continue using this method for the near term, but to explore a transition to differentiate between CO_2 captured for sequestration and CO_2 captured and used for EOR. In the future, the Ministry may treat captured CO_2 used for EOR as a coproduct, assigning a displacement coproduct credit rather than a sequestration credit. Further work is required to determine an appropriate emission factor.

Historically, entities modelling sequestration have entered the percent capture interchangeably with percent sequestered. Losses and leakage were not accounted for, and often assuming 100% of the captured CO_2 was permanently sequestered with no losses or leakage downstream. The current percent captured can be seen in Equation 2:

$$Percent\ captured = \frac{X_{captured}}{X_{produced}} \qquad \text{Equation 2}$$

Where:

- $X_{captured}$ is the quantity of CO_2 captured and delivered for sequestration, and
- $X_{produced}$ is the theoretical maximum quantity of CO_2 available to be captured based on the stoichiometry.

Currently in GHGenius 5.02b, fuel producers using CCS/CCUS will enter inputs into the sequestration sheet. GHGenius has no distinction between CCS and CCUS/EOR.

The sequestration percentage is entered into row 19, and energy inputs are entered in rows 22-26. The energy inputs include additional energy for capture, compression/dehydration, for transport, injection, and re-injection. Energy inputs, including electricity and fuel inputs should be directly measured. Energy inputs account for SSRs $P6_i$, $P7_i$, $P8_i$, and $P9_i$.

The percentage sequestered [Sequestration-Row 19] should reflect all emissions associated with the downstream activities of injection and recycling, including any leakage and fugitive emissions. The Ministry proposes to expand the system boundary to account for the up and downstream emissions by enforcing the input entered in the percentage sequestered cell as follows:

$$Percent\ sequestered\ = \frac{X_{injected} - X_{project,i} - X_{discount}}{X_{produced}}$$ *Equation 3*

where:

- $X_{injected}$ - the quantity of CO_2 (B1) captured and injected excluding minor emissions from CH_4 (B2) and N_2O (B3) may also be injected. B1 is Defined below in Equation 5.
- $X_{project,i}$ - the emissions associated with the sequestration (either CCS or EOR), calculated using Equation 6 and Equation 7 respectively. All emissions of CO_2, CH_4, and N_2O should be included as per Equation 4.
- $X_{discount}$ represents discounted emissions as a risk assurance mechanism to ensure permanent storage, as per Equation 1.
- $X_{produced}$ is the stoichiometric amount of CO_2 available from the fuel production process that would be vented to the atmosphere if not captured.

The total CO_2 equivalent (CO_2e) emissions is calculated using the Equation 4.

$$X_{CO2e} = \sum X_{CO2} * GWP_{CO2} + \sum X_{CH4} * GWP_{CH4} + \sum X_{N2O} * GWP_{N2O}$$ *Equation 4*

Here X_{CO2}, X_{CH4}, and X_{N2O} are the emissions and GWP_{CO2}, GWP_{CH4}, and GWP_{N2O} are the global warming potential of CO_2, CH_4, and N_2O respectively. GWP prescribed by the B.C. LCFS must be used for quantification[1].

The baseline emissions associated with the captures CO_2, $X_{injected}$ or B_1, are measured directly upstream of the point of injection effectively captures all upstream fugitive and

[1] https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/electricity-alternative-energy/transportation/renewable-low-carbon-fuels/rlcf011_-_approved_version_of_ghgenius_and_global_warming_potentialsdec2023.pdf

vented emissions. This is defined by Equation 5 below. Measurement/estimation of each variable used to compute the injected quantity is shown in Equation 11.

$$X_{injected} = B1 = X_{captured} - (P10_i + P11_i + P12_i + P13_i + P14_i + P15_i) \quad \text{Equation 5}$$

Here $X_{captured}$ is the quantity of CO_2 captured at the fuel production facility. $P10_i$-$P15_i$ do not require quantification as they are included by choosing the location of the baseline to be at the point of injection.

The project emissions for sequestration, $X_{project,CCS}$ is described in Equation 6. All SSRs must be measured or estimated and quantified according to Appendix B- .

$$X_{Project,CCS} = P3_{CCS} + P4_{CCS} + P16_{CCS} + P17_{CCS} + P18_{CCS} + P19_{CCS} \quad \text{Equation 6}$$

where:

- $P3_{CCS}$- Emissions from well drilling activities as per Equation 12.
- $P4_{CCS}$- Emissions associated with the production and delivery of materials used for carbon capture as per Equation 13.
- $P16_{CCS}$ - emissions from venting at the injection site as per Equation 14. This must include any CO_2 and CH_4, including that released for pressure management including brine production. Venting, whether planned or emergency, might be required during injection or production well workovers, mechanical integrity tests, and maintenance. All venting events should be recorded, noting the duration and the estimated quantities and composition of the gases released. Any downstream component of the injection meter must be included here.
- $P17_{CCS}$ - the emissions from fugitive emissions at injection and production wells as per Equation 15. These fugitive emissions occur from fittings, flanges, valves, connectors, meters, and headers associated with EOR operations. This must be done for all components downstream of the injection meter.
- $P18_{CCS}$ - emissions from the subsurface to atmosphere as per Equation 16.
- $P19_{CCS}$- loss, disposal, and recycling of materials used in the CO_2 capture process as per Equation 17.

The project emissions for CCUS/EOR, $X_{project,\ EOR}$ are described in Equation 7. All SSRs must be measured or estimated and quantified according to Appendix B- .

$$X_{Project,EOR} = P3_{EOR} + P4_{EOR} + P16_{EOR} + P17_{EOR} + P18_{EOR} + P19_{EOR} + P20_{EOR} + P22_{EOR} + P23_{EOR} \quad \text{Equation 7}$$

Where:

- $P3_{EOR}$ – the emissions that result from well drilling activities as per Equation 12.
- $P4_{EOR}$ – the production and delivery of materials used for carbon capture as per Equation 13.
- $P16_{EOR}$ - the emissions from venting at injection and production wells and in recycle stream as per Equation 14. Venting, whether planned or emergency,

might be required during injection or production well workovers, mechanical integrity tests, and maintenance. All venting events should be recorded, noting the duration and the estimated quantities and composition of the gases released. Any downstream component of the injection meter must be included here.

- $P17_{EOR}$ - the emissions from fugitive emissions at injection and production wells and in the recycle stream as per Equation 15. These fugitive emissions occur from fittings, flanges, valves, connectors, meters, and headers associated with EOR operations. This must be done for all components downstream of the injection meter.
- $P18_{EOR}$ - the emissions from subsurface to atmosphere as per Equation 16.
- $P19_{EOR}$ - the emissions from any flare at injection and production wells and in recycle stream as per Equation 18.
- $P20_{EOR}$ – Loss disposal, and recycling of materials used in the capture process as per Equation 17.
- $P22_{EOR}$ - any emissions entrained within products sold outside of product boundary as per Equation 19. This may include CO_2 entrained in produced water, natural gas, and crude oil. This can be excluded if it is reinjected into the same formation.
- $P23_{EOR}$ - any CO_2 transferred/sold outside project boundary as per Equation 20.

The injection project may receive CO_2 from multiple sources, in which case, the vented and fugitive emissions above can be prorated to adjust for the emissions attributed to a specific source. This would be done by using an attribution equation as follows:

$$a_V = \frac{\sum_{i=1}^{k} x_i}{\left(\sum_{i=1}^{k} x_i + \sum_{i=1}^{k} y_i\right)}$$

Equation 8

Here, a_V is the attribution factor, k is the current period venting and fugitive emissions are accruing, x is the quantity of CO_2 shipped from the fuel producer, and y is the CO_2 shipped by other parties.

8 Monitoring, Reporting, and Verification

This section outlines Monitoring, Reporting and Verification (MRV), also sometimes known as measurement, monitoring, and verification (MMRV). Project proponents must provide (M)MRV reports, subject to request by the ministry for compliance. Monitoring requirements are discussed in Appendix B- . (M)MRV reports, or equivalent, prepared for other jurisdictions may be requested at the Ministry's digression and operators are encouraged to send them as supplemental information during a Carbon Intensity Application and renewal.

The Ministry does not intend to impose additional MRV requirements beyond that of the local regulator. However, a monitoring plan must be in place and be designed based on the risk assessment and mitigation plan in the annual sequestration project report. The director can decline a project if the local regulator does not provide adequate rules surrounding monitoring to ensure confidence in permanence. Operators are encouraged to over-comply in this regard. Applicants should clearly summarize the (M)MRV approach for the CCUS, describing the project, the potential risks, and the corrective / preventative measures taken to mitigate those risks. A detailed list of programs that applicants must report on in each region will be released in an info bulletin, pre-approving certain areas the director has deemed to be adequately stringent to ensure permanence and transparency.

When an operator is given the option to report for sequestration activities, they are expected to comply with the relevant standards and opt in to that program.

For example, in the United States, EOR operators must report to the Environmental Protection Agency (EPA) Greenhouse Gas Reporting Program (GHGRP)[2] under subpart UU but are given the option to report also under Subpart RR. It is expected that to obtain credit under the B.C. LCFS for carbon sequestration, operators also report and follow the rules under subpart RR. In this example, Subpart VV/ISO 27916 may also be deemed sufficient to quantify the sequestration quantity.

8.1 Reporting

Below, what reports must be submitted, their contents, and at what frequency is stated.

8.1.1 Annual Sequestration Project Report

Fuel producers using CCS/CCUS must submit an annual sequestration project report in addition to their annual compliance reports. Annual sequestration reports must be submitted for the entirety of the injection phase, and after the injection phase has finished until a low or medium level of risk is achieved. A template will be provided in advance of the first compliance period. The annual sequestration project report will consist of two main sections, volumetric quantities of CO_2, and risk assessment and mitigation. The risk assessment and mitigation plan must identify any relevant risks, their probability of occurrence, magnitude of impact, and the mitigation measures in place to avoid/minimize these risks. This report may require verification by a third-party reviewer subject to LCFS policies and regulation, with a professional designation, either a professional geologist (P. Geo or equivalent), or a Professional Engineer (P. Eng or equivalent).

In the volumetric section of the report, producers will be required to report:

- The quantity of CO_2 captured
- The quantity of CO_2 injected

[2] https://www.epa.gov/ghgreporting

- The quantity of leaked CO_2, broken down into unplanned or planned leakage.
- Any changes to operations from the previous year

The risk assessment must:

- Quantify risk of CO_2 leakage from storage complex over 100-year post injection period
- Describe all potential pathways for leakage/migration of CO_2 from the storage complex. This includes any uncertainties identified during site characterization and well installation
- Identify potential scenarios that could arise as a result
- Complete computational modelling of CO_2 storage complex over 100-year timespan post injection. Results must be summarized and justified within the report.

Computational modelling must be completed as part of the risk assessment. Modelling must encompass the timeframe from the beginning of the project through the 100-years post injection. The model must:

- account for physical properties, site characteristics of the sequestration zone and injected CO_2 stream over the proposed life of the CCS project and incorporate operational data. This should be based on detailed geologic, hydrogeologic, and geo-mechanical data collected for characterization
- predict lateral and vertical migration of the free phase and dissolved CO_2 plume, from the time of injection to plume stabilization
- simulate any pertinent processes in geologic media based on scientific principles and accepted mathematical and governing principles. This includes multiphase flows of several fluids including ground water, CO_2, and hydrocarbons if present, as well as phase changes, and significant pressure changes.
- conduct a sensitivity analysis
- State any assumptions made, and identify areas where simplification was used.

The risk mitigation plan must:

- Summarize activities evaluated in risk assessment
- Highlight all risks, and rank them
- Outline the steps the project operator will take to manage, monitor, avoid, and minimize any risks.

The operator must use appropriate tools to characterize the potential adverse impacts to the environment, health, and/or safety by combining the probability of occurrence and the magnitude of occurrence. Risks must be quantified as either low, medium or high risk as per Table 4.

Table 4: Total risk based on probability and severity

	Severity of potential consequences			
Probability of occurrence over 100-years		**Insubstantial**	**Substantial**	**Catastrophic**
	>5%	Medium	High	High
	1-5%	Low	Medium	High
	<1%	Low	Medium	Medium

If the combined risk is high, annual sequestration project reports must continue to be submitted after injection has finished until a low or medium level of combined risk is achieved. Any risk identified with a medium level of combined risk must be included in an additional section of the report, the emergency and remedial response plan.

8.2 Verification

As with all other carbon intensity applications, any fuel code employing CCS will require third party verification as per the act, regulations, and info bulletins. Beyond the standard requirements, any project using CCS will require a specialist to review and sign off. The third-party verification is currently under development, and the details the Ministry intends to enforce are laid out in an intentions paper for public comment.

Specialists will be required for the verification of CCS projects. The specialist will need to have a valid P. Geo or P. Eng certification, with demonstrated experience and knowledge in the relevant field.

Third party verifiers need to ensure that any emissions reductions included in the LCA modelling for the B.C. LCFS, are not credited under another program.

Appendix A- SSR Diagram for CCS and EOR

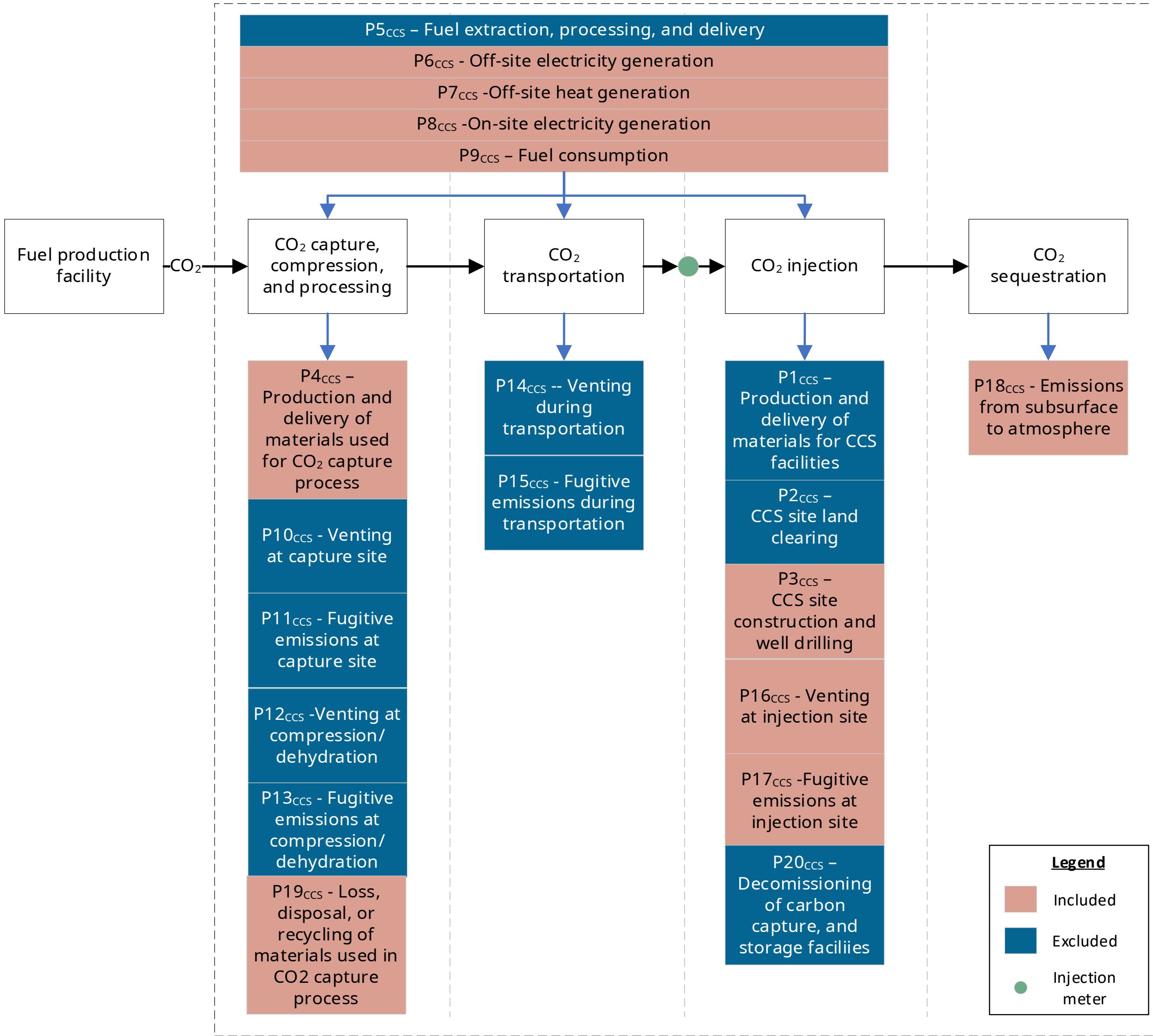

Figure 3: CCS SSRs

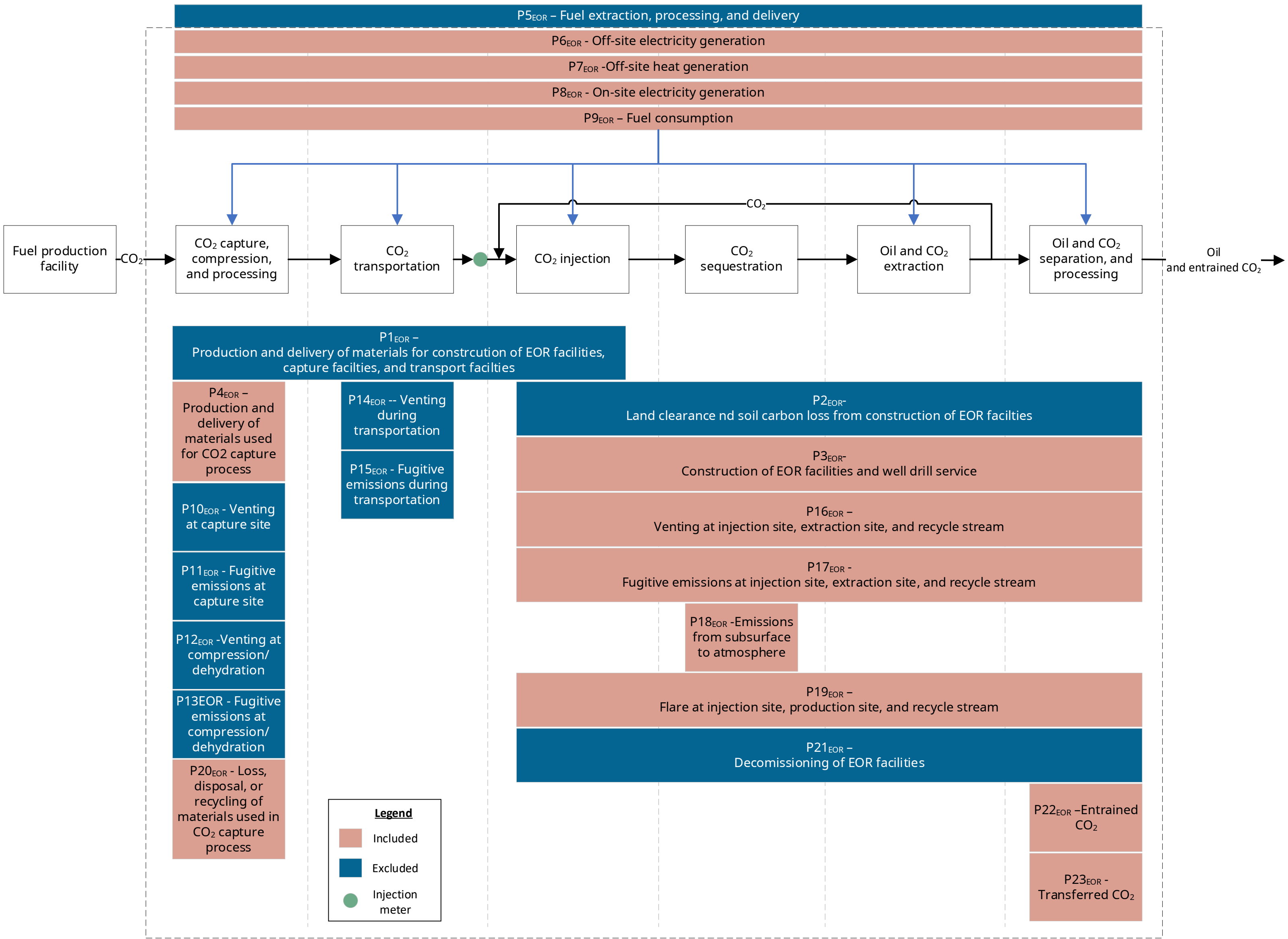

Figure 4: EOR SSR's

Appendix B- SSR Variables Quantification and Measurement

In this section, the quantification using measurement or estimation is explained. Any SSR with the subscript I applies to both CCS and EOR.

The decision whether each SSRs identified in subsection 6.1.2 and subsection 0 shall be measured or estimated was determined based on figure A.3- identifying and selecting SSRs from ISO 14064-2:2019. Figure A.3 can be summarized as follows:

1. Identify each SSR as either:
    a. controlled by the project,
    b. related to the project by energy or material flows into or out of the project,
    c. affected by the project through market changes
2. Ensure functional equivalence
3. Identify if emissions into/out of an SSR has changed
4. Assess data availability and cost effectiveness

While all ISO 14064-2 principles shall be adhered to during quantification, any SSR being measured shall place additional significance on must the principles of accuracy, and transparency, and any SSR being estimated shall place additional significance on conservativeness and transparency.

When referring to the Western Climate Initiative (WCI) methodologies, the most up to date version including any amendments should be used[3].

Fugitive and vented emission rates (ER)/factors (EF) are often given in terms of CH_4 emissions and need to be adjusted based on the molecular weight to quantify the CO_2 related emissions. The emission factors can be adjusted as follows.

Any equipment other than pipelines, the EF/ER can be adjusted using Equation 9.

$$CO_2\ EF = CH_4\ EF * \frac{MW_{CO2}}{MW_{CH4}} * \frac{mol\ \%\ CO2}{mol\ \%\ CH4} \quad \text{Equation 9}$$

[3] https://www2.gov.bc.ca/gov/content/environment/climate-change/industry/reporting/quantify

For CO_2 transport using underground pipelines, ER/EF's can be adjusted using Equation 10.

$$CO2\ EF = EF\ CH4 * \sqrt{\frac{44}{16}}$$

Equation 10

All SSR's are detailed in the following subsections.

B.1 B1- Injected CO_2

The injected quantity of CO_2 shown in Equation 11, is used for the baseline, and is the factor used for calculating the discounted emissions.

$$B1 = \sum (V_{injected,CO2} * C_{V,CO2} * \rho_{CO2})/1000 \quad \text{Equation 11}$$

Table 5: Measured/Estimated variables for B1

Variable	**Unit**	**Measured /Estimated**	**Method**	**Frequency**
$\boldsymbol{B1}$ Injected CO_2	t-CO_2e	N/A	N/A	N/A
$\boldsymbol{V_{injected,CO2}}$- Volume of injected gas	m^3	Measured	Direct metering of volume of gas using a meter located as close as possible to each injection wellhead but prior to re-injected fluid injection point.	Continuous, as high as possible
$\boldsymbol{C_{V,CO2}}$- Concentration of injected CO_2	% vol.	Measured	Directly measured downstream of the capture and processing equipment or upstream of the injection field at a custody transfer point. When additional CO_2 streams comingle with a capture stream of known concentration, the concentration of comingled stream must be confirmed either by direct measurement of the comingled stream or by mass balance and a measurement of the additional capture stream. The measurement sample point may occur downstream of the tie-in such that the concentration of the comingled stream is taken. Alternatively, the measurement can be taken downstream of the additional capture stream but upstream of comingling. In this case, the concentration of the	Minimum of daily samples averaged monthly on a volumetric basis.

Variable	Unit	Measured /Estimated	Method	Frequency
			comingled stream can be calculated by solving a single variable mass balance equation.	
ρ_{CO2}- Density of injected CO_2	kg/m^3	Estimated	Must use a reference density, corrected to the conditions at which the volumes of gas are reported. Data conversions from all pressure and temperature-compensated instruments must use the same pressure or temperature used for the specific meter calibration.	N/A

B.2 $P3_{CCS/EOR}$- Well Drilling Activity

The emissions from well drilling activity are described in Equation 12.

$$P3_{CCS/EOR} = \sum \frac{V_{gas\ kick} * C_{V,CO2,CH4,N2O} * \rho_{CO2,CH4,N2O}}{1000} * GWP_{CH4,N2O}$$

Equation 12

Table 6: Measured/Estimated variables for $P3_{CCS/EOR}$

Variable	Unit	Measured /Estimated	Method	Frequency
$P_{CCS/EOR}$- Well drilling activity emissions	t-CO_2e	N/A	N/A	N/A
$V_{gas\ kick}$- Volume of Vent Gas	m^3	Estimated	If the drilling activity resulted in a kick or a blowout, the volume of gas released must use an engineering estimate according to the relevant rules in the injection site jurisdiction. This may also be quantified using the WCI methodologies, equations 360-13 and 360-17 WCI.363(f). Emissions during well completion that are sent to flare stacks should be quantified according to subsection WCI.363(k), as described in Appendix section B.12 below.	Per event
$C_{V,CO2,CH4,N2O}$- Concentration of CO2, CH4 in Vent Gas	% vol.	Measured	Ideally A measured gas analysis should be obtained. If not possible, an estimation can be used with process knowledge and/or engineering estimates	Per event

Variable	Unit	Measured /Estimated	Method	Frequency
$\boldsymbol{\rho}_{CO2,CH4,N2O}$- Density of vented gas	Kg/m^3	Estimated	Must use a reference density, corrected to the conditions at which the volumes of gas are reported. Data conversions from all pressure and temperature compensated instruments must use the same pressure or temperature used for the specific meter calibration.	N/A
$GWP_{CH4,N2O}$- Global Warming Potential	Unitless	Estimated	Must use standard GWP's as published by B.C. LCFS[1].	N/A

B.3 $P4_{CCS/EOR}$- Production and delivery of capture materials

The emissions due to the production and delivery of capture materials is described in Equation 13.

$$P4_{CCS/EOR} = \sum Q_{materials,capture} * EF_{i,CO2,CH4,N2O}$$

Equation 13

Table 7: Measured/Estimated variables for $P4_{CCS/EOR}$

Variable	**Unit**	**Measured /Estimated**	**Method**	**Frequency**
$P4_{CCS/EOR}$- Production and Delivery of Material Inputs used in CO_2 Capture Process	t-CO_2e	N/A	N/A	N/A
$Q_{materials,capture}$- Quantity of material inputs consumed for carbon capture facility operation-	t/L/m^3 /other	Estimated	Estimation of the quantity of material inputs consumed for the EOR project based on engineering design documents.	Annual
$EF_{i,CO2,CH4,N2O}$- Emission factors for each type of material input /$Q_{materials,capture}$	t CO2e per t/L/ m^3/other	Estimated	Project specific design. Production and delivery estimates for the emission factors for the material inputs.	Annual

B.4 $P6_{CCS/EOR}$- Off-site Electricity Generation

Offsite electricity generation is accounted for within GHGenius. Users must enter the sum of all electricity usage related to capture, compression/dehydration/processing, transportation, injection and re-injection into the Sequestration sheet, in row 22 of the respective fuel pathway. Values should be entered into the model in kWh.

Table 8: Measured/Estimated variables for $P6_{CCS/EOR}$

Variable	**Unit**	**Measured /Estimated**	**Method**	**Frequency**
Electricity	kWh	Measured	Direct measurement of delivered electricity consumed at each facility involved in the capture, compression, transport, injection, storage, and re-injection of CO2.	Continuous

B.5 $P7_{CCS/EOR}$- Off-site heat generation

Heat generation is accounted for by entering energy consumption values in GHGenius Sequestration sheet, Rows 22-26. GHGenius expects inputs for electricity, diesel, natural gas, coal, and wood. Any heat used in the process for the capture, compression, transport, injection, storage, and re-injection of CO_2 must be accounted for.

Table 9: Measured/Estimated variables for $P7_{CCS/EOR}$

Variable	**Unit**	**Measured /Estimated**	**Method**	**Frequency**
Electricity	kWh	Measured	Direct measurement of delivered electricity consumed at each facility involved in the capture, compression, transport, injection, storage, and re-injection of CO2.	Continuous
Diesel	L	Measured	Direct measurement of delivered diesel consumed at each facility involved in the capture, compression, transport, injection, storage, and re-injection of CO2.	Continuous
Natural gas	MJ	Measured	Direct measurement of delivered natural gas consumed at each facility involved in the capture, compression, transport, injection, storage, and re-injection of CO2.	Continuous
Coal	kg	Measured	Direct measurement of delivered coal consumed at each facility involved in the capture, compression, transport, injection, storage, and re-injection of CO2.	Continuous
Wood	kg	Measured	Direct measurement of delivered wood or biomass consumed at each facility involved in the capture, compression, transport, injection, storage, and re-injection of CO2.	Continuous

B.6 $P8_{CCS/EOR}$-Onsite Electricity Generation

Onsite electricity generation is accounted for within GHGenius. Users must enter the sum of all electricity usage related to capture, compression/dehydration/processing, transportation, injection and re-injection into the Sequestration sheet, in row 22 of the respective fuel pathway. Values should be entered into the model in kWh.

Table 10: Measured/Estimated variables for $P8_{CCS/EOR}$

Variable	**Unit**	**Measured /Estimated**	**Method**	**Frequency**
Electricity	kWh	Measured	Direct measurement of delivered electricity consumed at each facility involved in the capture, compression, transport, injection, storage, and re-injection of CO2.	Continuous

B.7 $P9_{CCS/EOR}$- Fuel consumption

Any other fuel consumption not accounted for in previous SSRs is accounted for by entering energy consumption values in GHGenius Sequestration sheet, Rows 22-26. GHGenius expects inputs for electricity, diesel, natural gas, coal, and wood. Any fuels used in the process for the capture, compression, transport, injection, storage, and re-injection of CO_2 must be accounted for.

Table 11: Measured/Estimated variables for $P7_{CCS/EOR}$

Variable	**Unit**	**Measured /Estimated**	**Method**	**Frequency**
Electricity	kWh	Measured	Direct measurement of delivered electricity consumed at each facility involved in the capture, compression, transport, injection, storage, and re-injection of CO2.	Continuous
Diesel	L	Measured	Direct measurement of delivered diesel consumed at each facility involved in the capture, compression, transport, injection, storage, and re-injection of CO2.	Continuous
Natural gas	MJ	Measured	Direct measurement of delivered natural gas consumed at each facility involved in the capture, compression, transport, injection, storage, and re-injection of CO2.	Continuous
Coal	kg	Measured	Direct measurement of delivered coal consumed at each facility involved in the capture, compression, transport, injection, storage, and re-injection of CO2.	Continuous
Wood	kg	Measured	Direct measurement of delivered wood or biomass consumed at each facility involved in the capture, compression, transport, injection, storage, and re-injection of CO2.	Continuous

B.8 $P16_{CCS/EOR}$- Venting at Injection Sites, Production/Extraction, and Recycling Streams

Venting at injection sites for CCS/EOR is accounted for using an event-based approach. Instances of venting must be logged, including the duration of the venting event and the estimated quantities and makeup of gases vented. For EOR, venting must be included at production sites, and recycling stream. The emissions associated with venting at the injection sites, production/extraction sites, and recycling streams is calculated using Equation 14.

$$P16_{CCS/EOR} = \sum V_{vent} * C_{V,CO2} * \rho_{CO2}$$

Equation 14

Table 12: Measured/Estimated variables for $P16_{CCS/EOR}$

Variable	Unit	Measured /Estimated	Method	Frequency
$P16_{CCS/EOR}$- Venting at Injection Well Sites /and production, and recycling stream (EOR)	t-CO_2e	N/A	N/A	N/A
V_{vent}- Volume of Vent Gas	m^3	Estimated	Estimate volume based on the duration of venting and quantified according to the WCI methodology for each piece of equipment listed in Table 13. All components downstream of the injection meter must be included for quantification. This includes any equipment necessary for extraction, processing/separation of CO_2, recycling, and re-injection as applicable.	A minimum of daily samples averaged monthly on volumetric basis
$C_{V,CO2}$- Composition in Vent Gas	%	Measured	The gas composition shall be directly measured during the event. Otherwise, operations data will be needed for an engineering estimate.	A minimum of daily samples averaged monthly on volumetric basis

Variable	**Unit**	**Measured /Estimated**	**Method**	**Frequency**
ρ_{CO2}- Density of Vent Gas		Estimated	Must use a reference density, corrected to the conditions at which the volumes of gas are reported. Data conversions from all pressure and temperature compensated instruments must be sure to use the same pressure or temperature used for the specific meter calibration.	N/A

Table 13 below states the equipment and sources of venting that must be logged and quantified.

Table 13: Venting emissions volume quantification for CCS and EOR

Equipment/SSR	**Quantification methodology**
Metered and un-metered natural gas pneumatic device and pump	WCI.363(a), WCI.363(a.1), WCI.363(b), and WCI.363(b.1)
Equipment and pipeline blowdowns	WCI.363(g), WCI.363(r), WCI.363(s), and WCI.363(t)
Centrifugal compressor	WCI.363(l)
Reciprocating compressor	WCI.363(m)

B.9 $P17_{CCS/EOR}$- Fugitive emissions at injection sites /and production/recycle streams

Calculate the fugitive emissions using the equipment count method for any component downstream of the injection meter. For EOR, the production, and recycling stream must also be included. Fugitive emissions are calculated as per Equation 15.

$$P17_{CCS/EOR} = \sum N_i * ER_i * C_{V,CO2,CH4,N2O} + Other\ fugitive\ releases$$

Equation 15

Table 14: Measured/Estimated variables for $P17_{CCS/EOR}$

Variable	**Unit**	**Measured /Estimated**	**Method**	**Frequency**
$\boldsymbol{P17_{CCS}}$- Fugitive Emissions at Injection Well Sites /and production and recycle stream (EOR)	t-CO_2e	N/A	N/A	N/A
$\boldsymbol{N_i}$- Number of Sources after Injection Meter	N/A	Estimated	Project-specific design. Downstream of the injection meter, count each component listed in WCI.362(d)(9): valves, connectors, open ended lines, pressure relief valves and meters. In addition, the count should include other equipment leak sources such as instruments, loading arms, stuffing boxes, compressor seals, dump lever arms, and breather caps. For EOR, components in the production, and recycle stream must be included. Alternatively, count the number of major pieces of equipment and multiply by the number of	Once and if changes are made to plant.

Variable	**Unit**	**Measured /Estimated**	**Method**	**Frequency**
			components per major piece of equipment to arrive at the total number of each component for the facility.	
ER_i- Emission Rate/factor for Source	t-gas/ source/ year	Measured and/or estimated	Emission factors developed using site specific measured data are preferred. Emission factors developed using measured data should follow WCI.363(n). All equipment listed in WCI.362(d)(9) must be tested following either WCI.364(a)(0.1) or WCI.364(a)(0.2). If an emission factor cannot be developed according to WCI.363(n), operators may use default emission factors from Table 7-12 of the API's Compendium of Greenhouse Gas Emissions Methodologies for the Natural Gas and Oil Industry from 2021[4]. Note that emission factors may be given for CH_4 and will need to be converted to be used for CO_2 as described in the document	Annually
$C_{V,CO2,CH4,N2O}$- Molar Composition in Fugitive Gas	%	Measure or estimated	Measurement preferred method. Engineering estimates of gas composition are acceptable in the absence of measured gas analysis	A minimum of daily samples, when possible. Otherwise, estimated composition of the vented gas based on its source.
$\textit{Other fugitive releases}$	t-CO_2e	Estimated	Engineering Estimate	Per occurrence

[4] https://www.api.org/-/media/files/policy/esg/ghg/2021-api-ghg-compendium-110921.pdf

Example:

In this example, the calculation is conducted for one component type. The applicant must conduct similar calculations for the other equipment types listed in WCI.362(d)(9): valves, connectors, open ended lines, pressure relief valves and meters.

By using the Piping and Instrumentation Diagram (P&ID), and confirming by onsite inspection, an EOR operator identifies 10 valves within the CO_2 recycling stream. Concentration measurements are taken immediately downstream of the separation units, where CO_2 is sent into the recycling stream. In this example, the gas contains 96.20 mol% CO_2, 3.43 mol % CH_4, and 0.36 mol % of other minor constituents [5]. The 0.36% mol % of other constituents is considered negligible in this example as the composition breakdown is unknown. Here, measured emission factors cannot be determined using WCI.363(n), so the operator will use EF factors from table 7-12 of the API's Compendium of Greenhouse Gas Emissions Methodologies for the Natural Gas and Oil Industry from 2021. In this example, 7000 hours of operation per year is assumed, but actual hours per year should be recorded and used in calculations.

The emissions from valves are calculated by using the following equation:

$$P17_{EOR,\ valves} = P17_{EOR,\ valves,\ CH4} * GWP_{CH4} + P17_{EOR,\ valves,\ CO2} * GWP_{CO2}$$

1. Compute $P17_{EOR,\ valves,\ CH4}$ -

$$P17_{EOR,\ valves,\ CH4} = N_{valves} * ER_{valves,\ CH4} * C_{V,\ CH4}$$

$$P17_{EOR,\ valves,\ CH4} = 10 \text{ valves} * (2.94E\text{-}6 \text{ t-}CH_4\text{/valve*hr} * 7000\text{hrs/yr}) * 0.0343$$

$$\mathbf{P17_{EOR,\ valves,\ CH4} = 0.00706\ t\text{-}CH_4/yr}$$

2. Compute $P17_{EOR,\ valves,\ CO2}$ –

$$P17_{EOR,\ valves,\ CO2} = N_{valves} * ER_{valves,\ CO2} * C_{V,\ CO2}$$

Here Equation 9 is used to convert the emission rate for CH_4 to CO_2.

[5] https://www.sciencedirect.com/science/article/abs/pii/S1750583618302172

$$ER_{valves,CO2} = ER_{valves,CH4} * \frac{MW_{CO2}}{MW_{CH4}} * \frac{mol\ \%\ CO_2}{mol\ \%\ CH_4}$$

$$ER_{valves,CO2} = 2.94 * 10^{-6}\ t\ CH_4/hr * \frac{44.01\ g/mol}{16.04\ g/mol} * \frac{96.20\ mol\ \%\ CO_2}{3.43\ mol\ \%\ CH_4}$$

$$ER_{valves,CO2} = 0.000226\ t\frac{CO_2}{hr}$$

Therefore:

$$P17_{EOR,\ valves,\ CO2} = N_{valves} * ER_{valves,\ CO2} * C_{V,\ CO2}$$

$$P17_{EOR,\ valves,\ CO2} = 10\ valves * (0.000226\ t\text{-}CO_2/valve*hr * 7000hrs/yr) * 0.9620$$

$$\mathbf{P17_{EOR,\ valves,\ CO2} = 0.00218\ t\text{-}CO_2/yr}$$

3. Compute $P17_{EOR,\ valves}$-

$$P17_{EOR,\ valves} = P17_{EOR,\ valves,\ CH4} * GWP_{CH4} + P17_{EOR,\ valves,\ CO2} * GWP_{CO2}$$

$$P17_{EOR,\ valves} = P17_{EOR,\ valves,\ CH4} * GWP_{CH4} + P17_{EOR,\ valves,\ CO2} * GWP_{CO2}$$

$$P17_{EOR,\ valves} = 0.00706\ t\text{-}CH_4/yr * 30 + 0.00218\ t\text{-}CO_2/yr * 1$$

$$\mathbf{P17_{EOR,\ valves} = 0.214\ t\text{-}CO_2e/yr}$$

B.10 $P18_{CCS/EOR}$- Subsurface to Atmosphere Emissions

Unintentional atmospheric emissions can happen due to gas migrating through unnoticed faults, fractures, or subsurface equipment caused by damaged casing, cement, wellhead, packer, or tubing. CO_2 that escapes from the designated storage area but stays underground is treated the same as if it had leaked into the atmosphere and must be measured accordingly. This also includes deliberate releases, removals, transfers of CO_2, or net reversals.

Direct measurement is likely not possible, so operators may rely on an engineering estimate, while accounting for uncertainty. The ISO 14064-2 principle of conservativeness is paramount here. The mass of CO_2 leaked from the subsurface is described in Equation 16. Justification for the chosen detection limit and estimation methodology needs to be provided.

$$P18_{CCS/EOR} = \sum M_{leaked\ CO2}$$

Equation 16

Table 15: Measured/Estimated variables for $P18_{CCS/EOR}$

Variable	**Unit**	**Measured /Estimated**	**Method**	**Frequency**
$P18_{CCS/EOR}$	t-CO_2e	N/A	N/A	N/A
$M_{leaked\ CO2}$	t-CO_2e	Estimated	Subsurface leakage will equal to the half of the detection limit of the chosen method, or the actual leakage volume itself, whichever is larger. In addition, the uncertainty associated with the amount leaked must be stated or estimated. If uncertainty is estimated, justification must be provided by a qualified professional in the field of geology. The uncertainty threshold is 7.5%. If the absolute value of uncertainty is greater than 7.5%, the actual absolute uncertainty must be added to the value reported.	Per occurrence

For example, an applicant measuring 100t-CO_2e subsurface leakage with an uncertainty of 10%, the applicant would report 110t-CO_2e (100t-CO_2e + 0.1*100t-CO_2e).

If an applicant measured 100t-CO_2e with a certainty of +-5%, they would report 100t-CO_2e, since the 5% is within the uncertainty threshold.

B.11 $P19_{CCS}/P20_{EOR}$ - Loss, Disposal, or Recycling of Materials Used in CO_2 Capture Processes

The emissions associated with the loss, disposal, and recycling of materials used for carbon capture are calculated as per Equation 17.

Equation 17

$$P19_{CCS} = P20_{EOR} = \sum V_{capture\ material\ i} * EF_{capture\ material\ i,CO2,CH4,N2O}$$

Table 16: Measured/Estimated variables for $P19_{CCS}/P20_{EOR}$

Variable	Unit	Measured /Estimated	Method	Frequency
$\boldsymbol{P19_{CCS}/P20_{EOR}}$ Loss, Disposal or Recycling of Material i Used in CO2 Capture Processes	t-CO_2e	N/A	N/A	N/A
$\boldsymbol{V_{capture\ material\ i}}$- Volume of material i consumed	L/m^3/ other	Estimated	Estimation of the volume of material inputs lost, disposed or recycled for the carbon capture and storage project. The engineering report will specify the volume of material input lost, disposed of or recycled for an appropriately sized carbon capture and storage facility.	
$\boldsymbol{EF_{capture\ material\ i,CO2,CH4,N2O}}$- Emissions factor for each type of material i	tCO_2e	Estimated	Project-specific design. Production and delivery estimates for the emission factors for the material inputs.	

B.12 $P19_{EOR}$- Emissions from flaring at injection, production, and CO_2 recycling stream

The emissions from flaring need to be calculated for any flaring that takes place at the injection, production, and CO_2 recycle stream. Flaring emissions are calculated using the WCI methodologies, in section WCI.363(k)[3]. Combusted and un-combusted emissions must be accounted for and summed together using Equation 18.

$$P19_{EOR} = \sum E_i * \rho_i * GWP_i \qquad \text{Equation 18}$$

Table 17: Measured/Estimated variables for $P19_{EOR}$

Variable	Unit	Measured /Estimated	Method	Frequency
$\boldsymbol{P19_{EOR}}$- Flare at injection and production wells and in recycle stream	t-CO_2e	N/A	N/A	N/A
$\boldsymbol{E_i}$- Volumetric emissions of each GHG from flaring	Sm^3	Calculated/measured/estimated	Contribution of annual combusted and non-combusted gas i (CH_4, CO_2, and N_2O). From WCI.363(k), gasses i are calculated using equation 360-27, equation 360-30, and equation 360-31 for CH_4, CO_2, and N_2O respectively.	Continuous
$\boldsymbol{\rho_i}$- Density of gas i (CH_4, CO_2, and N_2O)	Kg/Sm^3	Measured	Must use a reference density, corrected to the conditions at which the volumes of gas are reported.	Continuous
GWP_i-	Unitless	Estimated	Must use standard GWP's as published by B.C. LCFS[1].	N/A

Variable	**Unit**	**Measured /Estimated**	**Method**	**Frequency**
Global Warming Potential				

B.13 $P22_{EOR}$- Entrained CO_2

Entrained CO_2 is contained in products leaving the site. Measurements for entrained CO_2 must be taken directly downstream of the CO_2 separation units on the non CO_2 recycle stream.

$$P22_{EOR} = \left(V_{gas} * C_{V,gas,CO2} * \frac{\rho_{CO2}}{1000}\right) + \left(M_{water} * C_{M,water,CO2}\right) + \left(M_{oil} * C_{M,oil,CO2}\right) \qquad \text{Equation 19}$$

Table 18: Measured/Estimated variables for $P22_{EOR}$

Variable	**Unit**	**Measured /Estimated**	**Method**	**Frequency**
$\boldsymbol{P22_{EOR}}$- Entrained CO_2	t-CO_2e	N/A	N/A	N/A
$\boldsymbol{V_{gas}}$- Volume of natural gas or fuel gas, produced from the formation that CO_2 is being injected into, that is sold to third parties or input into a natural gas pipeline in year.	m^3/year	Measured	Measured at standard conditions immediately downstream of the CO_2 separation unit for the recycling stream that will not be reinjected into the formation.	Continuous
$\boldsymbol{C_{V,gas,CO2}}$- Concentration of CO_2 as a percent volume in produced natural gas or fuel gas sold to third parties or input	%	Measured	The gas composition shall be directly measured immediately downstream of the CO_2 separation and recycling unit during production.	A minimum of daily samples averaged monthly on volumetric basis
$\boldsymbol{\rho_{CO2}}$- Density of CO_2	Kg/m^3	Estimated	Must use a reference density, corrected to the conditions at which the volumes of gas are reported. Data conversions from all pressure and temperature compensated instruments must	N/A

Variable	**Unit**	**Measured /Estimated**	**Method**	**Frequency**
			be sure to use the same pressure or temperature used for the specific meter calibration.	
M_{water}- Mass of water produced from the formation that CO_2 is being injected into, that is disposed of or otherwise not re-injected back into the formation	t-water/year	Measured	The mass of water leaving the CO_2 separation unit not being reinjected shall be directly measured downstream of the CO_2 separation unit for recycling/reinjection.	Continuous
$C_{M,water,CO2}$- Mass fraction of CO_2 in the water produced from the formation.	%	Measured	The water composition shall be directly measured immediately downstream of the CO_2 separation and recycling unit during production.	A minimum of daily samples averaged monthly on volumetric basis
M_{oil}- Mass of crude oil and other hydrocarbons produced from the formation that CO_2 is being injected into	t-oil/y	Measured	The mass of oil leaving the CO_2 separation unit that is not being reinjected shall be directly measured.	Continuous
$C_{M,oil,CO2}$)- Mass fraction of CO_2 in the crude oil and other hydrocarbons produced from the formation	%	Measured	The oil composition shall be directly measured immediately downstream of the CO_2 separation and recycling unit during production.	A minimum of daily samples averaged monthly on volumetric basis

B.14 $P23_{EOR}$ - Transferred CO_2

$$P23_{EOR} = \sum M_{CO2}$$

Equation 20

Table 19: Measured/Estimated variables for $P23_{EOR}$

Variable	**Unit**	**Measured /Estimated**	**Method**	**Frequency**
$P23_{EOR}$- Transferred CO_2	t-CO_2e	N/A	N/A	N/A
M_{CO2}- Mass of CO_2 sold/transferred outside of plant boundary	t-CO_2e	Measured	Any CO_2 injected, extracted, not re-injected, that is sold or transferred to another entity. Measurement must be taken directly downstream of the CO_2 separation process before leaving the plant boundary.	Continuous