JOGMEC's guideline for safe, long-term containment of CO_2 using CO2-EOR (JOGMEC CO_2-EOR Guideline)

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（JOGMEC）

Contents

1 Introduction

1.1 Background and objectives

For the energy transition toward the realization of carbon neutrality by 2050, a comprehensive approach that considers the social and economic impacts on people's lives is necessary. The International Energy Agency (IEA) stated that the transition to clean energy must be advanced along with the efforts to provide energy access for all people by 2030[1]. Fossil fuels that enable stable and massive power generation continue to play an important role in smooth energy transitions. Although fossil fuels emit greenhouse gases (GHGs) during combustion, it is possible to mitigate climate change when they are combined with carbon dioxide (CO_2) capture and storage (CCS), where the emitted CO_2 is captured and sequestrated in subsurface formations.

To promote better use of fossil fuels that contributes to climate change mitigation, Japan Organization for Metals and Energy Security (JOGMEC) published the following two guidelines in May 2022: "CCS guideline (1st version)" and "GHG/CI guideline (1st version)." The former guideline is concerned with technical guidance on a CCS project and quantification of net CO_2 reduction with a CCS project[2], while the latter is concerned with the quantification of the reduction in GHG emissions associated with the production of liquefied natural gas (LNG), hydrogen, and ammonia[3].

Following these publications, JOGMEC has recently started the development of the guideline for CO_2-enhanced oil recovery (CO_2-EOR) in which CO_2 is injected into a hydrocarbon reservoir to enhance hydrocarbon recovery from the reservoir.

There are several opinions on whether CO_2-EOR contributes to the mitigation of climate change by reducing GHG emissions. It is believed that CO_2-EOR does not contribute to a reduction in GHG emissions because it produces additional oil[4]. For this, Clean Air Task Force (CATF) introduced the concept of displacement. Based on the global oil market analysis by IEA, CATF proposed that additional oil produced with CO_2-EOR does not increase the global oil supply; instead, it displaces the oil produced using conventional methods, from the market while maintaining a certain level of global oil supply determined from global demand. They concluded that every barrel of oil produced with CO_2-EOR reduced CO_2 emissions by 37% compared to oil produced using conventional methods[5].

Others have claimed that the life-cycle emissions of CO_2-EOR projects could be net-positive. Because CO_2-EOR produces oil while injecting CO_2 if the amount of GHG emissions associated with the combustion of the produced oil exceeds the amount of CO_2 stored, the life-cycle emissions of such a CO_2-EOR project result in positive emissions. However, recently, several researchers and EOR operators have shown that the life-cycle emissions of CO_2-EOR projects can be net negative if the projects are properly designed to improve the efficiency of CO_2 storage[6,7].

Moreover, the most remarkable feature of CO_2-EOR is that it reduces GHG emissions while generating revenue from the oil produced. Hence, CO_2-EOR facilitates a sustainable and smooth energy transition because it achieves both CO_2 sequestration and energy production, yielding economic incentives that enable an operator to proceed with further development of decarbonization technologies. This feature is particularly important for countries that need to cope with their growing energy demand. Several countries have encouraged the implementation of CO_2-EOR.

Considering the aforementioned points, JOGMEC views CO_2-EOR as an effective means of reducing GHG emissions and encourages its implementation during a period of energy transition toward a decarbonized society. Nevertheless, such CO_2-EOR can contribute to a reduction in GHG emissions only when a project is properly planned and executed with the objective of safe and long-term containment of CO_2.

Hence, JOGMEC started the preparation of guidelines for CO_2-EOR contributing to a reduction in GHG emissions. These guidelines have the following four objectives:

- To state JOGMEC's view on CO_2-EOR, i.e., we consider CO_2-EOR to be an effective means of GHG reduction during the energy transition period, and we encourage its implementation.
- To provide technical guidance for the implementation of CO_2-EOR projects that contribute to a reduction in GHG emissions and for the quantification of emission reductions by such projects.
- To provide technical guidance that is recommended to be satisfied by companies for receiving financial and/or technical support from JOGMEC for such projects.
- To help interested business entities and regulators design their business models and regulations to reduce the carbon intensity of energy fuels through safe and long-term storage of CO_2.

1.2 Contents of the guideline

This guideline provides technical recommendations for project planning and operations of CO_2-EOR that are conducted for safe and long-term containment of CO_2, and quantification of the reduction in GHG emissions with such projects. Sections 1.3 and 1.4 provide the scope and features of the guidelines, respectively.

Section 2 describes the details of the project planning and operations of CO_2 storage projects in association with CO_2-EOR, and Section 3 provides a methodology to quantify the amount of reduction in GHG emissions that can be achieved with these CO_2-EOR projects.

To formulate the guidelines, we considered the views of international organizations, financial institutions, and government agencies on whether CO_2-EOR can be regarded as a useful GHG emission reduction measure. Furthermore, to consider the technical recommendations for safe and long-term storage of CO_2, we referred to the rules and regulations of the countries and regions where laws and regulations for safe and long-term storage of CO_2 and the technical requirements of various systems that deal with carbon credits and tax incentives in association with CO_2-EOR are in place (Appendix 1).

1.3 Scope of the guideline

1.3.1 Scope of projects

This guideline is designed for a project in which CO_2 is injected into hydrocarbon reservoirs with dual objectives of "enhanced hydrocarbon recovery" and "safe and long-term containment of CO_2." The guideline covers CO_2-enhanced oil and gas recovery (CO_2-EOR and CO_2-EGR) projects that contribute to reducing GHG emissions. Hereafter, the terms CO_2-EOR and EOR refer to both CO_2-EOR and CO_2-EGR.

Projects that do not recover hydrocarbon resources from a target reservoir from the beginning of the project are beyond the scope of this guideline (e.g., CO_2 injection in saline aquifers and in depleted oil/gas reservoirs). For these types of projects, please refer to the JOGMEC's CCS guideline[2].

1.3.2 Scope of project stages

The scope of the project stages of this guideline covers the pre-injection to post-injection periods, as shown in Figure 1. The definitions of each project stage are as follows.

- Pre-injection period: the project period before the injection of CO_2 into the reservoir begins. During this period, hydrocarbon production from the project reservoir without CO_2 injection is performed normally.
- During the injection period: the project period from the time at which CO_2 injection in a target reservoir begins to the time at which both CO_2 injection and hydrocarbon production cease. In this guideline, regardless of natural CO_2 or anthropogenic CO_2, as long as CO_2 injection occurs, such a project stage belongs to this period. Even if the CO_2 injection ceases, if production takes place in a project reservoir, the project stage belongs to this period.
- Post-injection period: The project period after the cessation of both injection and production of CO_2 till the time approved by the local project authority for the termination of the project.*
- Post-termination period: The period after the time approved by the local project authority for the termination of the project.
- Quantification period: The project period during which the reduction in GHG emissions is

quantified. This period begins after the injection of CO_2 by an EOR operator and ends at the termination of the EOR project with the approval of a local authority.

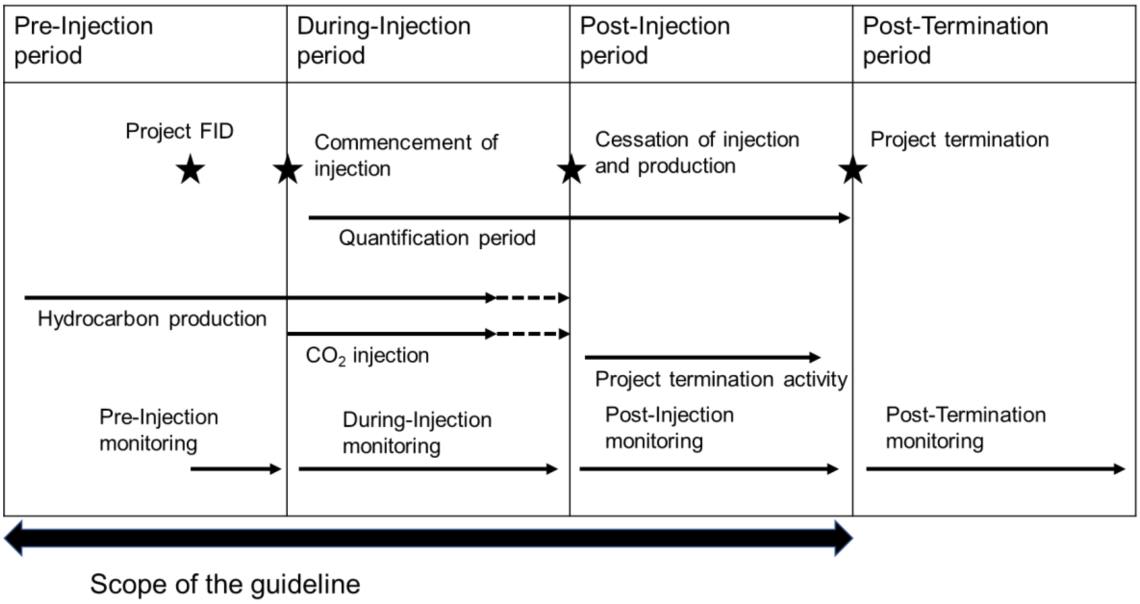

Figure 1: Scope of project stages of this guideline (prepared by JOGMEC)

(NOTE) The beginning of the post-injection period: This guideline defines the beginning of the post-injection period as the time at which both CO_2 injection and hydrocarbon production cease. In general, the following three cases are considered for a typical CO_2-EOR project: (1) both production and injection cease, (2) production continues while injection ceases, and (3) production ceases while injection continues; hence, the project transforms into CCS. This guideline covers all three cases.

1.3.3 Scope of a spatial boundary

In this guideline, the spatial boundary of a CO_2-EOR project is defined to include the following surface and subsurface elements, as shown in Figure 2.

- CO_2 reception and injection facilities (including storage tanks, etc.)
- Processing and storage facilities for the oil produced.
- Processing facilities for the produced gas (including CO_2 recovery units)
- Target subsurface geological formations (EOR complex*)

(NOTE) EOR complex: This is the same as defined in ISO27916[8], that is, subsurface formations composed of at least one target reservoir formation where CO_2 is injected and the cap rock formation acts as a barrier.

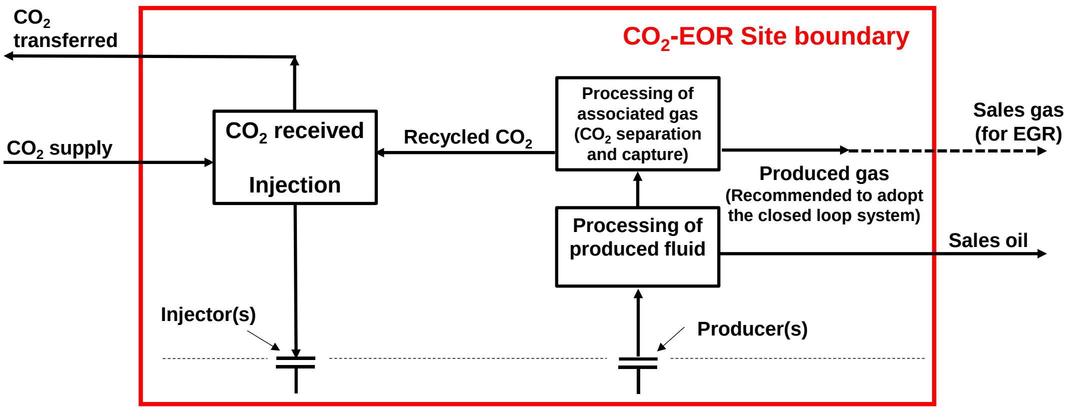

Figure 2: Scope of a spatial boundary of this guideline (prepared by JOGMEC).

Within the spatial boundary of the CO_2-EOR project in this guideline are the CO_2 reception and injection facilities, CO_2 injector(s), hydrocarbon producer(s), and processing facilities for the produced fluid (oil, gas, and water). In some projects, the received CO_2 is transferred to other CO_2-EOR projects located outside the boundary. In some cases, the outgoing CO_2 from the boundary contains the transferred CO_2 stream. If the received CO_2 has sufficient pressure, there is no need for an injection facility. As the configuration of EOR facilities varies on a project-by-project basis, the specific spatial boundary is determined by an EOR operator who reviews each component of the facilities relevant to an EOR project.

GHG (CO_2 and CH_4) emissions from the elements constituting the EOR project are measured. In addition, any input from outside to inside the boundary is measured. For instance, GHG emissions associated with fuel consumption by the pumps and/or compressors within the boundary are measured.

1.4 Features of the guideline

1.4.1 Effect of reduction in GHG emissions with CO_2-EOR

Compared with CO_2 storage in saline aquifers and/or depleted oil/gas reservoirs, CO_2-EOR has a lower contribution to the reduction in GHG emissions because it produces hydrocarbons that can, in turn, contribute to CO_2 emissions (Scope 3 emissions with CO_2-EOR projects). However, there is a consensus that CO_2-EOR safely stores a certain amount of CO_2 within an EOR complex, that is, a certain amount of injected CO_2 remains in the EOR complex for a long period, with several trapping mechanisms, such as capillary trapping, solubility trapping, and structural trapping.

Another opinion is that CO_2-EOR does not contribute to a reduction in GHG emissions because it produces hydrocarbons. For this, Clean Air Task Force (CATF) introduced the concept of displacement, that is, additional oil produced with CO_2-EOR does not contribute to additional GHG emissions because it displaces crude oil in the global market whose amount remains within a certain range (because the amount is determined from the balance between demand and supply)[5]. The concept of displacement has been employed in several institutes, such as the American Carbon Registry (ACR)[9] and Alberta Emission Offset System (AEOS)[10]. JOGMEC also supports the concept of displacement and drafts this guideline.

Based on the above, in this guideline, JOGMEC considers the safe and long-term containment of CO_2 associated with CO_2-EOR as an effective means of GHG reduction, at least during the period of energy transition toward a decarbonized society.

1.4.2 Technical recommendations for safe and long-term containment of CO_2 in association with CO_2-EOR

(1) General technical recommendations

As technical recommendations for the safe and long-term containment of CO_2 in association with CO_2-EOR, these guidelines recommend planning and operating CO_2-EOR projects in compliance with ISO27916[8] which is an international standard for CO_2-EOR. Furthermore, these guidelines provide additional technical recommendations for ISO27916[8].

(2) Scope of the quantification of reduction in GHG emissions

Following the concept described in the JOGMEC CCS guideline[2], the scope of the quantification of the reduction in GHG emissions in this guideline includes Scope 1 and Scope 2 emissions associated with a CO_2-EOR project, where GHG refers to CO_2 and CH_4. N_2O is excluded from the definition of GHG in this guideline because its amount of emission is much lower than that of CO_2; however, if there is combustion equipment in an EOR boundary, it is recommended to confirm that the amount of N_2O emissions is sufficiently small compared to that of CO_2 by direct measurements.

(NOTE)
Scope 1 emissions: Direct GHG emissions by the project operator (fuel combustion).
Scope 2 emissions: Indirect GHG emissions associated with the supplied power and heat/steam from outside the EOR boundary.

(3) Improving storage efficiency

A CO_2-EOR project, designed mainly to maximize the recovery of hydrocarbons from a project reservoir, produces hydrocarbons while injecting CO_2. Hence, it is necessary to allow the outgoing CO_2 from an EOR boundary as entrained CO_2 in the hydrocarbon. The amount of CO_2 (entrained CO_2

in the hydrocarbon, oil, and/or gas stream) must be quantified and subtracted from injected CO_2 amount to determine the net CO_2 stored.

When an EOR operator aims at high CO_2 storage efficiency, it is recommended to consume all the produced hydrocarbon gas within the EOR boundary or to employ a closed-loop system that is commonly applied in onshore CO_2-EOR projects in the U.S[11]. In a closed-loop system, all the produced gas streams are directly transferred to the injection stream without separation from the produced gas stream. Hence, all produced gas streams are compressed and used for re-injection from the injectors. As this creates a closed loop between the surface facilities and a subsurface reservoir, it has been reported that 90–95% of the received CO_2 is securely stored within an EOR complex[11].

(4) Expandability of CO_2-EOR projects

In a CO_2-EOR project, the efficiency of CO_2 storage changes as the EOR process progresses. The project maintains a high CO_2 storage efficiency from the beginning of CO_2 injection until the occurrence of CO_2 breakthrough to producers. After the CO_2 breakthrough, the efficiency of CO_2 storage decreases as the concentration of CO_2 in the produced gas stream increases. However, regardless of the progress of the EOR process, because an agreed amount of CO_2 from an emitter is continuously delivered to the EOR site, a CO_2-EOR project must have sufficient expandability to receive the agreed amount.

Examples of a CO_2-EOR project that has expandability are projects that are connected to other EOR and/or CCS sites via CO_2 transportation pipelines and a project that is developed by a phased approach in which a vast EOR site is gradually developed by applying a flooding pattern (composed of a set of producers and injectors). For these types of projects, it is recommended that the CO_2 storage capacity of each EOR site should be evaluated before CO_2 injection, based on reservoir simulations.

It should be noted that for a project that is connected to other EOR sites and/or CCS sites via CO_2 transportation pipelines, multiple CO_2 sources (emitters) and multiple CO_2 sinks (EOR/CCS operators) are connected via pipelines; hence, attempts to monitor and verify the supply-demand balance of the entire system of pipelines will be important in the future.

(5) Post-injection monitoring

For CO_2-EOR projects designed for safe and long-term CO_2 containment, it is strongly recommended to perform post-injection monitoring for a certain duration during the post-injection period.

2 Project planning and operations of CO_2 storage projects in association with CO_2-EOR

2.1 General remarks and fundamental concepts

In many countries and regions, CO_2-EOR is executed under the existing regulations for the exploration and production of oil and gas. However, when an operator executes a CO_2-EOR project with the objective of safe and long-term CO_2 containment in addition to enhanced hydrocarbon recovery, these projects must satisfy the requirements to ensure safe and long-term CO_2 containment, in addition to the requirements defined by the regulations for the exploration and production of oil and gas. If an operator executes an EOR project in a region where rules and regulations for safe and long-term CO_2 containment are in place, compliance with these rules and regulations is recommended.

In this guideline, to ensure safe and long-term containment of CO_2, in principle, it is recommended to comply with ISO27916. The guidelines provide additional recommendations for ISO27916 in the following sections. To consider these additional recommendations, we referred to other rules for the safe and long-term containment of CO_2 such as ISO27914[12] (international standard for geological sequestration of CO_2), ACR, Clean Development Mechanism (CDM), and rules by the Environmental Protection Agency (EPA) of the U.S. (UIC Class II and VI[13], and the reporting requirement of subpart RR[14]).

2.2 Documentation

For the execution and operation of a CO_2-EOR project, it is recommended to prepare and maintain all the documents relevant to the CO_2-EOR project comply with clauses 4.1_ 4.4 in ISO27916.
[Reference: ISO27916 4.1 _ 4.4]

In addition, although clause 4.3 in ISO27916 requires the preparation of an EOR operation management plan, initial containment assurance, and monitoring program as initial documentation, it is recommended that an initial termination plan also be prepared and revised depending on the progress of the project.

2.3 Information gathering for the preparation of the EOR operations management plan

For the preparation of the EOR operations management plan, it is recommended to gather and analyze the following information in compliance with clauses 5.1_ 5.5 in ISO27916.

- General description of the CO_2-EOR project (geology of the EOR complex, facilities, well infrastructure, development history).
- Geological characterization and containment assessment of the EOR complex.
- Description of facilities within the CO_2-EOR project.
- Existing wells within the EOR complex

- Operations history of the project reservoir

[Reference: ISO27916 5.1_5.5]

In addition, the guideline recommends the followings:

- The level of information required to characterize the geology and assess the containment of CO_2 in the EOR complex is the level at which a geological and reservoir simulation model can be constructed.
- In many CO_2-EOR projects, subsurface data have been acquired during the historical hydrocarbon development period before CO_2-EOR begins. However, if these data are not sufficient to characterize the geology and assess the containment of CO_2 in the EOR complex, acquiring new data (e.g., drilling evaluation wells) before CO_2 injection is recommended.
- It is recommended to prepare a process flow diagram (PFD) that includes facilities within a CO_2-EOR project and describes the flow of CO_2 and produced oil and gas. In the PFD, it is recommended that the locations of venting, fluid sampling, and metering should be clearly described. The metering of fluids is particularly important for quantifying the amount of net CO_2 stored; hence, it is recommended to clearly describe the metering method and its accuracy.
- It is recommended to investigate all existing wells within an EOR complex and gather information on the latest status of these wells (wellhead and wellbore) as much as possible. In cases where it is difficult to evaluate the current status of the wells from historical well records, it is recommended to conduct on-site surveys of these wells to gather their information.

2.4 Preparation of the EOR operations management plan

In the preparation of the EOR operations management plan, it is recommended that the procedures for field management be clearly described, as described in (a)–(i) in Clause 6.1.1 of ISO27916.

[Reference: ISO27916 6.1.1]

In addition, the guideline recommends the following:

- (Expandability of a CO_2-EOR project) It is recommended to ensure that the EOR operations management plan can stably accept the agreed amount of CO_2 stream over the project period. It is recommended that the CO_2 storage capacity of a project is recommended to be evaluated based on reservoir simulation models before CO_2 injection.
- (Simulation models) It is recommended to construct geological and reservoir models and plan projects based on the geological characterization and containment assessment of the EOR complex using these models [ACR 5.4.1.3].
- (Improving predictability) Before CO_2 injection, it is recommended that the best effort be made to improve the predictability of the CO_2-EOR project by performing history matching of the

historical hydrocarbon production period using the aforementioned models. During the CO_2 injection period, it is recommended to continue periodic model revisions [ACR 5.4.1.3].

- (Risk management and monitoring plan) It is recommended to prepare a risk management plan (see Section 2.5) based on risk assessment and a monitoring plan (see Section 2.6).
- (Post-injection monitoring) It is recommended to plan and conduct "during-injection monitoring" and "post-injection monitoring" for a certain period (see Section 2.6).
- (Termination plan) It is recommended to prepare an appropriate plan for project termination to enable smooth liability transfer from an EOR operator to a local authority while ensuring safe and long-term CO_2 containment (see Section 2.9). In particular, caution is required in EOR projects that are implemented based on regulations related to the exploration and production of oil and gas. An EOR project has to be terminated not only upon fulfilling the requirements in the regulations but also upon fulfilling the requirements to ensure safe and long-term CO_2 containment.

2.5 Risk management

A risk-management plan should be prepared based on the identification of potential CO_2 leakage pathways and their risk assessments. It is strongly recommended to conduct risk management assessment as a part of containment assurance in compliant with clauses 6.1.2 _ 6.1.3 in ISO27916 as follows:

- Initial containment assurance
- Operational containment assurance

[Reference: ISO27916 6.1.2 ~ 6.1.3]

In addition, the guideline recommends the followings:

- (Identification of potential CO_2 leakage pathways) It is recommended to identify potential CO_2 leakage pathways through the site characterization based on the construction of geological models and reservoir simulations [ACR 5.4.1.2]. If the identified risks exceed the allowable limit, the EOR site is excluded from the candidate list.
- (Well integrity assessment) It is recommended that a list of wells be prepared for all existing wells located within an influence zone. This influence zone is determined by considering the expected spread of CO_2 (including the spread of the CO_2 plume and pressure disturbance) and other risks specific to an EOR project. It is recommended that the list of wells should include the current status, how and when they are completed, information relevant to plugs and abandonments, and available cement bond logs [ACR 5.4.1.2]. If it is not possible to prepare a list of all existing wells located within an influence zone, the reasons for this should be described.
- (Well integrity assessment and remediation) It is recommended to define technical requirements

to ensure the integrity of wells and to conduct an assessment of well integrity to check if all wells satisfy the requirements. For wells in which issues in integrity are identified, it is recommended to plan countermeasures to recover their integrity and execute those before CO_2 injection where necessary. Examples of countermeasures are well remediation and monitoring of leakage [ACR 5.4.1.2]. If it is not possible to perform a integrity assessment for all existing wells located within an influence zone, the reasons for the same have to be described.

- (Natural and induced seismicity) It is recommended to exclude an area from a candidate site for a project, in cases where significant seismic activities are observed compared to other areas and where it is not possible to acquire background data relevant to seismic activities before CO_2 injection [JOGMEC CCS guideline chapter 2, 2.2]. During the operation of CO_2-EOR, it is recommended to devise and maintain surface seismic arrays to distinguish operation-related induced seismicity from natural seismicity [LCFS[15] 4.3.2.3].

2.6 Monitoring

The objectives of monitoring are mainly classified into two categories: (1) ensuring safe and long-term containment of CO_2 and (2) providing evidence for the quantification of reduction in GHG. Here, we describe the monitoring of the former objective, while that of the latter is described in Section 3.3.

It is strongly recommended to plan and conduct monitoring to ensure safe and long-term containment of CO_2 in compliance with clauses 6.2.1_6.2.3 of ISO27916 as follows:

- Monitoring of potential leakage pathways
- Monitoring methods
- Monitoring program implementation

[Reference: ISO27916 6.1.2_6.1.3]

In addition, the guideline strongly recommends the following:

- (Monitoring requirements equivalent to those for CCS) It is recommended to make monitoring plans equivalent to those for CO_2 storage in geological formations, that is, it is recommended to prepare a monitoring plan in compliance with clause 9 of ISO27914 which is an international standard for CO_2 storage in geological formations. Hence, it is recommended to plan and conduct the monitoring for at least the following three periods.
    - Pre-injection period monitoring： [ISO27914 9.2.2]
    - During-injection period monitoring： [ISO27914 9.2.3]
    - Post-injection (Closure) period monitoring： [ISO27914 9.2.4]

  For the selection of specific monitoring techniques, it is recommended to choose cost-effective techniques by referring to the best practices of former CCS projects. Examples of specific monitoring techniques are provided in clause 6.4 in the JOGMEC CCS guidelines.

- (Acquisition of baseline data) While ISO27914 requires the acquisition of baseline data before CO_2 injection, in case such data is difficult to acquire, it is recommended to propose how to rigorously determine baseline data.
- (Use of well data) EOR operations involve fluid production from the producers, unlike CO_2 storage in geological formations. Data acquisition on the amount of produced fluid, temperature, and pressure is normally conducted as a part of normal EOR operations. These data can be used through history matching using the simulation model described in Section 2.4 to evaluate the spread of the CO_2 plume and the pressure disturbance. It is recommended to use these production data for monitoring.

2.7 Well infrastructures

It is highly recommended to construct new infrastructure in compliance with clause 7.1 of ISO27916. It is strongly recommended that an operator ensure the placement of proper cement for long-term CO_2 containment, at least in the cap rock section.
[Reference: ISO27916 7.1gh]

It is highly recommended to conduct well intervention in compliance with clause 7.2 of ISO27916.
[Reference: ISO27916 7.2]

It is strongly recommended that, during the transition period toward a decarbonized society, as described in Section 1.1, all new wells involved in a CO_2-EOR operation must comply with existing standards used for the exploration and production of oil and gas (e.g., API standards, UIC Class II in the U.S.) [ACR 5.4.1.2]. Additionally, it is strongly recommended that mechanical integrity and corrosion protection tests should be conducted periodically. It is also recommended that an operator aims to comply with well requirements equivalent to UIC Class VI in the future.

2.8 Record keeping and missing data

It is recommended to maintain records relevant to CO_2-EOR operations in compliance with clause 9.1 in ISO27916 and to prepare for submission to a local authority upon request after the termination of the project. If it is difficult to acquire actual measured data, it is recommended to describe a method to estimate missing data in compliance with clause 9.2 of ISO27916.
[Reference: ISO27916 9.1 ~ 9.2]

2.9 Project termination

It is recommended to terminate a project in compliance with clause 10.1_10.6 of ISO27916 as follows:

- General
- Periodic assurance of containment
- Termination plan
- Requisites for termination
- CO_2-EOR project termination
- Post-termination

[Reference: ISO27916 10.1_10.6]

In addition, the guideline recommends the following:

- (Requirements for project termination) For the termination of CO_2-EOR that enables safe and long-term containment of CO_2, it is recommended to fulfil not only the requirements set by a local authority that deal with hydrocarbon development but also the requirements that ensure safe and long-term containment of CO_2.
- (Requirements ensuring containment of CO_2) In case a CO_2-EOR project occurs in a region where a local authority has requirements ensuring safe and long-term containment of CO_2, and the project is executed in compliance with these requirements, it is recommended to terminate the project in accordance with the requirements.
- (Requirements ensuring containment of CO_2) In case a CO_2-EOR project occurs in a region where a local authority does not have requirements ensuring safe and long-term containment of CO_2, and the project is executed under the regulations for hydrocarbon development, in principle, it is recommended to terminate the project following the project termination plan which describes the details corresponding to a) _ e) of the clause 10.4 in ISO27916. In particular, if a project achieves these conditions, these must be confirmed and verified through post-injection monitoring (NOTE1). The requirements for and duration of post-injection and post-termination monitoring are recommended to be discussed and agreed upon among the relevant stakeholders (NOTE2) before CO_2 injection, and these requirements should be documented as an initial termination plan.

(NOTE 1) Currently, the majority of CO_2-EOR projects are executed onshore in the United States under the rules of UIC Class II, which do not aim for long-term CO_2 containment. If an operator terminates a project under the rules of UIC Class II, the operator loses the right to enter the EOR site, making it impossible for the operator to conduct post-injection monitoring. Even in such a case, it is recommended to conduct post-injection monitoring as described in the note in Section 1.3.2, i.e., (2) a case in which production continues, while injection ceases, and (3) a case in which production ceases, while injection continues, hence, the project transforms to CCS.

(NOTE 2) The relevant stakeholders include at least the following:

- An EOR operator and a local authority who is responsible for the EOR project.
- A CO_2 supplier if a CO_2-EOR project contributes to the reduction of GHG emissions of the supplier.

3 Quantification of reduction in GHG emissions of CO_2 storage projects in association with CO_2-EOR

3.1 General remarks and fundamental concepts

Section 3 provides guidance for the quantification of the reduction in GHG emissions with CO_2-EOR which aims at the safe and long-term containment of CO_2.

To quantify the reduction in GHG emissions, this guideline recommends quantifying the amount of net CO_2 stored in compliance with clause 8 of ISO27916. In addition, this guideline describes how to quantify the emissions associated with fuel and power consumption in an EOR boundary and the leakage of CH_4 from an EOR boundary.

Methodologies to quantify the reduction in GHG emissions with CO_2-EOR are currently being actively discussed and investigated by several institutes worldwide, and they differ for each CO_2-EOR project depending on the location and characteristics of the project. Hence, the methodologies described in this guideline represent JOGMEC's current view on this matter (during the transition to a decarbonized society). JOGMEC will continue to review and improve the content of the guidelines as necessary.

3.2 Quantification of reduction in GHG emissions

It is recommended that the amount of net CO_2 is stored in compliance with clause 8 of ISO27916. Clause 8 in ISO27916 provides the CO_2 that is counted as storage and the CO_2 that is subtracted from storage (for instance, the loss of CO_2). Although, in many cases, when the received CO_2 from outside an EOR boundary is injected into a target reservoir, GHG emissions such as loss, flare, and venting at the facilities of injection, processing of produced streams, etc., must be subtracted to derive the net-CO_2 storage. The types of CO_2 considered in this guideline are compliant with the following:

- CO_2 to be included in storage amount: [Reference: ISO27916 1.3.1]
- CO_2 to be excluded from storage amount: [Reference: ISO27916 1.3.2]

In addition, this guideline recommends quantifying the following to derive the reduction in GHG emissions:

- Scope 1 and scope 2 emissions within an EOR boundary
- CH_4 leakage from an EOR boundary. Note that because CO_2 leakage from an EOR boundary is counted by the methodology to quantify net-CO_2 storage in clause 8 of ISO27916, it is not

included here.

(NOTE) JOGMEC Guidelines on Quantification of CO_2/GHG Emissions and Carbon Intensity.
JOGMEC published "GHG/CI guideline (1st version)" in May 2022. This guideline provides the quantification of reductions in GHG emissions associated with the production of liquefied natural gas, hydrogen, and ammonia. The GHG/CI guidelines aim to provide accurate and rigorous methodologies to quantify the level of emissions based on the estimation using emission intensity and activity amount and/or the estimation combining direct measurement and material balance method. Please refer to the GHG/CI guidelines for the specific methodologies used for these estimation methods.

3.2.1 Quantification of CO_2 storage amount based on ISO27916

Clause 8 in ISO27196 provides methodologies for quantifying the amount of net-CO_2 storage (m_{stored}) by subtracting the amount of operational loss and leakage from an EOR complex from the amount of CO_2 received (CO_2 input), which is given by

$$m_{\text{stored}} = m_{\text{input}} - m_{\text{loss operations}} - m_{\text{loss EOR complex}}$$

where m_{input} denotes the CO_2 input, $m_{\text{loss operations}}$ denotes the operational loss, and $m_{\text{loss EOR complex}}$ denotes the leakage from an EOR complex. The parameters required to determine these quantities are described in the following sections of ISO27916.

- General [Reference: ISO27916 8.1]
- Quantification principle [Reference: ISO27916 8.2]
- Quantification of input [Reference: ISO27916 8.3]
- Quantification of loss [Reference: ISO27916 8.4.1_8.4.5]
- Quantification of leakage from an EOX complex [Reference: ISO27916 8.4.6]

In this guideline, only anthropogenic CO_2 is considered as the amount of net-CO_2 storage. The definition of anthropogenic CO_2 in this guideline is the same as that in ISO 27916. If a project deals with both anthropogenic and non-anthropogenic CO_2, the amount of anthropogenic CO_2 must be allocated based on the methodology described in clause 8.5 in ISO27916.

- Definition of anthropogenic CO_2 [Reference: ISO27916 3.1]
- Allocation ratio for anthropogenic CO_2 [Reference: ISO27916 8.5]

Table 1 provides examples of anthropogenic CO_2 considered in this guideline. It is highly recommended to discuss and agree on the anthropogenic portion of CO_2 of a project before CO_2 injection with relevant stakeholders*.

(NOTE) The meaning of "relevant stakeholders" is the same as described in Section 2.9.

Table 1: Examples of the scope of CO_2 that is included or excluded in this guideline

Examples	Scope
CO_2 produced as a by-product of combustion and chemical processes. (e.g., recovered CO_2 from post combustion exhaust gas from power plants, recovered CO_2 from chemical processes of ammonia/hydrogen production.)	Included in CO_2 storage quantification
CO_2 produced from subsurface reservoirs in association with hydrocarbon development. (e.g., separated CO_2 from hydrocarbon gas stream containing high CO_2 concentration)	Included in CO_2 storage quantification
CO_2 produced from subsurface reservoirs only for the purpose of use of CO_2. (e.g., produced CO_2 from subsurface CO_2 reservoirs such as the Jackson Dome in the U.S.)	Excluded from CO_2 storage quantification

In a CO_2-EOR project, recycled CO_2 from the produced fluids is mixed with CO_2 received from outside the EOR boundary, pressurized to the injection pressure, and re-injected into a target reservoir from the injectors. After the CO_2 breakthrough for producers, the gas associated with crude oil production contains a high concentration of CO_2. Hence, it is necessary to properly recover and reinject this produced CO_2. The gas stream after the separation of CO_2 contains mainly methane, and it is possible to send it to the market as sales gas. However, even after CO_2 separation, because this outgoing gas contains CO_2, the storage efficiency of a project can decrease, which contradicts the objective of CO_2 storage. Hence, this guideline recommends adopting a closed-loop system that is commonly used in projects in the onshore U.S. If an EOR operator sells the associated gas after the separation of CO_2, it is necessary to quantify the amount of CO_2 entrained in the sales gas and outgoing from the EOR boundary.

3.2.2 Emissions associated with fuel and power consumptions (scope 1 and scope 2)

The scope of the power and heat/steam to be counted depends on the facilities and flow scheme of each project. Hence, it is recommended to clarify the scope of power and heat/steam to be counted during the project planning stage (pre-injection period) to avoid double counting and omission of GHG emissions. Once CO_2 injection begins (during the injection period), it is recommended to monitor the status of operations to verify whether the actual emissions are consistent with the planned emissions.

3.2.3 Methane leakage from an EOR site boundary

Leakages from an EOR site boundary are classified into two types:1) intended releases based on an operation plan, such as flares and vents, and 2) unintended releases, such as leakages and emergency releases. This guideline recommends quantifying the amount of CH_4 leakage from an EOR site boundary since CO_2 leakage is covered in clause 8 of ISO27916.

3.2.4 Quantification of the reduction in GHG emissions

The quantification of the reduction in GHG emissions associated with a CO_2-EOR project (Figure 3) is given by the following equation: The details of each term in the equations are listed in Table 2.

[Reduction in GHG emissions associated with CO_2-EOR project]

= [CO_2 storage amount based on ISO27916]

− [Emissions associated with fuel and power consumption (Scopes 1 and 2)]

− [Methane leakage from the EOR site boundary]

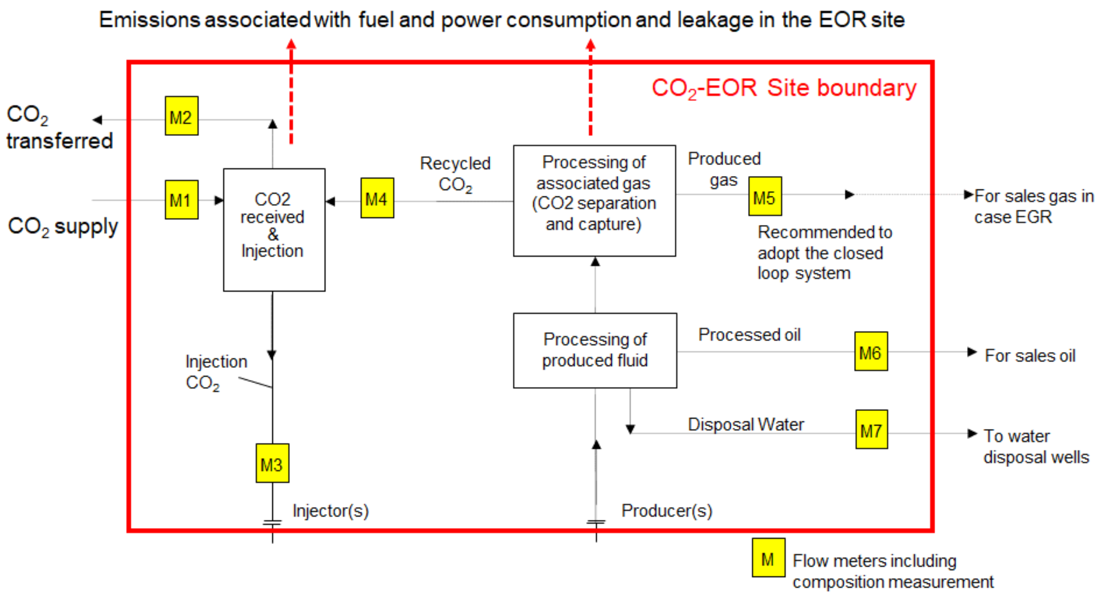

Figure 3: Schematic of a typical CO_2-EOR project (prepared by JOGMEC).

Table 2: Quantification of the reduction in GHG emissions in association with a CO_2-EOR project.

Term	Descriptions
Reduction in the GHG emissions in association with a CO_2-EOR project	Reduction in the GHG emissions that is achieved by a CO_2-EOR project designed for safe and long-term containment of CO_2
CO_2 storage amount based on ISO27916	This is determined based on the clause 8 of ISO27916. Annex B in ISO27916 provides an example of this calculation, please refer to this for details. In case emission intensity and activity amount are used, please refer to the chapter 2 of JOGMEC's GHG/CI guideline (version 2), recommended methodology at the site (such as EPA Subpart W[16], etc.) or commonly recognized methodologies. The unit of CO_2 storage amount is "ton".
Emissions associated with fuel and power consumptions (scope 1 and scope 2)	The total of the following emissions associated with CO_2 receipt, compression, processing of produced fluids, CO_2 recycling, monitoring, etc. (1) Direct CO_2/GHG emissions associated with fuel combustion (for generation of power and heat/steam). This is Scope 1 emission and please refer to the chapter 2 of JOGMEC's GHG/CI guideline (version 2) (2) Indirect CO_2/GHG emissions associated with purchased electricity (for generation of power and heat/steam). This is Scope 2 emission and please refer to the chapter 2 of JOGMEC's GHG/CI guideline (version 2)
Methane leakage from an EOR site boundary	Intended releases of methane such as flare and vent occurring at CO_2 recovery and other facilities, methane leakage occurring during the process of compression, transportation, and injection (only in case methane is used for fuel gas). This is determined based on emission intensity. Please refer to the chapter 2 of JOGMEC's GHG/CI guideline (version 2), recommended methodology at the site (such as EPA Subpart W[16], etc.) or commonly recognized methods.

GHG: greenhouse gas; EGR: enhanced gas recovery; EOR: enhanced oil recovery

3.3 Measurements during CO_2-EOR operations

Depending on the purpose, the required level of accuracy for measuring the amount of CO_2 within an EOR site boundary varies. Although there is no established international standard for measurements with a clear description of the required level of accuracy, this guideline recommends the following measurements, as listed in Table **3**.

Table 3: Summary of the recommendations for measurement.

Parameters	Unit	Frequency	Comment
Gas flow rate, CO_2 concentration and CO_2 flow rate at custody transfer meters (M1 and M2, plus M5 for CO_2-EGR projects)	Nm^3/d % ton/d	● Continuous for gas flow rate. ● Preferable to measure gas composition at every 3_5 minutes but depending on a project.	● Measure gas flow rate at a custody transfer meter and install a gas chromatography at an appropriate point close to the custody transfer meter to measure gas composition. ● Correct measured flow rate with pressure and temperature; and try to avoid using estimated composition and density which are not based on measurements. ● Install flow meters in accordance with guidance by a vendor. ● Place flow meters at least at the point of M1 and M2 for CO_2-EOR projects and plus M3 for CO_2-EGR projects. No need to place at M5 if a closed loop system is employed. ● Make calibration and inspection of flow meters periodically in accordance with specifications by a vendor and/or regulations by a local authority. ● Obtain CO_2 flow rate in mass unit (ton/d) from volumetric flow rate obtained from gas flow rate and CO_2 concentration.
Gas flow rate, CO_2 concentration and CO_2 flow rate at operational meters (M3 and M4)	Nm^3/d % ton/d	● Continuous for gas flow rate. ● Periodic gas composition measurement based on laboratory analysis on collected samples.	● Measure gas flow rate at operational flow meters, collect fluid samples from sampling points located close to the flow meters, and conduct gas composition analysis on the samples. ● Correct measured flow rate with pressure and temperature; and try to avoid using estimated composition and density which are not based on measurements. ● Install flow meters in accordance with guidance by a vendor.

		• The frequency of analysis depends on a project.	• Place flow meters at least at the point of M3 and M4. • Make calibration and inspection of flow meters periodically in accordance with specifications by a vendor and/or regulations by a local authority. • Obtain CO_2 flow rate in mass unit (ton/d) from volumetric flow meter obtained from gas flow rate and CO_2 concentration.
Oil flow rate, CO_2 concentration and CO_2 flow rate at custody transfer meters (M6)	ton/d % ton/d	• Continuous for oil flow rate. • Periodic composition and density measurement at a frequency required from oil custody transfer	• Install flow meters in accordance with guidance by a vendor. • Make calibration and inspection of meters periodically in accordance with specifications by a vendor and/or regulations by a local authority.
Water flow rate, CO_2 concentration and CO_2 flow rate at water disposal (M7)	ton/d % ton/d	• Continuous for water flow rate. • Periodic composition measurement based on laboratory analysis on collected samples. • The frequency of analysis depends on a project.	• Install flow meters in accordance with guidance by a vendor. • Make calibration and inspection of flow meters periodically in accordance with specifications by a vendor and/or regulations by a local authority. • Measure the composition and density based on analyses performed on collected samples; and use measured CO_2 concentration as a representative value. • Locate sampling points close to metering points. • In case water flow rate measurement is not conducted, make periodical measurement of CO_2 concentration in water to ensure the amount of CO_2 in water remains at a sufficiently low level.

GHG: greenhouse gas; EGR: enhanced gas recovery; EOR: enhanced oil recovery

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5 Appendix

Appendix 1: Technical requirements defined in different schemes that include CO_2-EOR as a mean of CO_2 storage (as of December 2022)

Disclaimer

JOGMEC strives to post as accurate information as possible regarding this guideline but does not necessarily guarantee the accuracy and completeness of the content. Please note that JOGMEC is not responsible for any damage incurred as a result of following these guidelines.

Appendix 1

Appendix 1: Technical requirements defined in different schemes that include CO_2-EOR as a mean of CO_2 storage (as of December 2022)

NOTE: *The American Carbon Registry (ACR)* is a voluntary carbon offset program; *The Clean Development Mechanism (CDM)*, defined in Article 12 of the Protocol, allows a country with an emission-reduction or emission-limitation commitment under the Kyoto Protocol (Annex B Party) to implement an emission-reduction project in developing countries; *EPA Class II plus Subpart RR* is the requirements for CO_2 enhanced oil recovery in the US in the 45Q Tax Credit[1]; *EPA Class VI plus Subpart RR* is the requirement for CO_2 geologic sequestration in the US in the 45Q Tax Credit[1]; the *Alberta Emission Offset System (AEOS)* is a regulatory program that enables facilities regulated under the Carbon Competitiveness Incentive Regulation to purchase and retire emission offsets to meet compliance obligations.

The following table is modified from Gupta and Cumming, 2016 [2] with reference to the original documents for each rule.

	ACR: American Carbon Registry[3]	**CDM:** Clean Development Mechanism, Modalities and Procedures for CCS[4]	**EPA Class II plus Subpart RR:** Environmental Protection Agency (EPA) Class II[5] plus Reporting via Subpart RR[6]	**EPA Class VI plus Subpart RR:** Environmental Protection Agency (EPA) Class VI[5] plus Reporting via Subpart RR[6]	**Protocol for AEOS:** Quantification Protocol for EOR for AEOS[7] (Alberta Emission Offset System)
Risk Assessment and Mitigation	● File Risk Mitigation Covenant or similar, including ACR right to access property to conduct inspections [ACR 1.2]. ● Identify leakage pathways and remediate where possible [ACR 5.4.1]. ● Develop a catalog of wells penetrating at or near the injection zone; repair or monitor wells with leakage potential [ACR 5.4.1.2]. ● Undertake a simulation study of potential storage failure scenarios, considering a range of uncertainty for parameters and site characteristics [ACR 5.4.1.1].	● Perform risk and safety assessment for the entire CCS chain (not just storage), periodically updated to reflect monitoring data. ● Develop remedial measures and response plans to stop or control unintended CO_2 emissions or leakage (F. Participation requirement). ● Perform environmental and socio-economic impact assessments, periodically updated to reflect monitoring data.	● **Subpart RR** requires: ➢ Delineate the maximum monitoring area – the area expected to contain the free phase CO_2 plume until injected CO_2 is not expected to migrate in the future in a manner likely to result in surface leakage or release [§ 98.448]. ➢ Identify potential surface leakage pathways in the maximum monitoring area and assess the likelihood, magnitude, and timing, of surface leakage of CO_2 through these pathways [§ 98.448].	● **Subpart RR** requires the same as on the left. ● **UIC Class VI** has its original requirements relevant to risk assessment and mitigation as follows: ➢ Prepare information on the seismic history and a tabulation of all wells within the area of review [§ 146.82]; ➢ Identify all artificial penetrations that may penetrate the confining zone and either confirm that those have mechanical integrity if operational or have been properly plugged. Corrective action must be performed on any artificial penetrations that could serve as leakage pathways [§ 146.84 c]. ➢ Be based on detailed geologic data collected [§146.84 c]; ➢ Take into account any geologic heterogeneities, other discontinuities, data quality, and their possible impact on model predictions [§146.84 c]; and ➢ Consider potential migration through faults, fractures, and artificial penetrations [§146.84 c].	● Establish a site-specific risk assessment that will allow for thorough risk management throughout the life of scheme approval, ● assess the risks associated with storage and remediation strategies in case of loss of containment. ● A wellbore risk assessment that reviews new and existing wellbores within 1.6 km beyond the CO_2 fluid plume to assess for and manage risks over the life of the CO_2-EOR storage approval. ● Any high-risk offset wells within 100 metres of a proposed injection well may need to be abandoned as per Directive 020. ● A hazard assessment evaluating the potential for induced seismicity within the maximum CO_2 plume extent and the applied for CO_2 EOR storage scheme approval area.

Pre-Injection Characterization and Monitoring	● Operator has the option to decide if pre-injection data is needed [5.4.1.3]. ● Storage volume expected to contain CO_2, plume extent and duration of plume migration must be assessed via the use of a reservoir model and flow simulations [ACR 5.4.1.1]. ● Identify leakage pathways and remediate where possible. Operator must develop a detailed catalog of wells penetrating at or near the injection zone and proceed to repair or monitor wells with leakage potential [ACR 5.4.1.2].	● Perform monitoring to establish baseline data. ● Assess all known and inferred structures within the injection and cap rock formations for risk of migration of injected CO_2 via a 3D reservoir model (Appendix B). ● Assess the injected CO_2 fate and migration, with a particular focus on vetting for risks of seepage to surface. ● Develop a monitoring plan, site preparation, well construction, injection rates and pressures, O&M protocols, and timing and management of site closure based on the results of the above fluid flow and simulation study. ● Describe the process for history matching and use the monitoring data to calibrate and update numerical models. ● Monitoring plan must be periodically updated to reflect the analysis of the monitoring data.	● **Subpart RR** requires: ➢ Define a strategy for setting monitoring baselines for surface leakage [§ 98.448]. ➢ Define a strategy for detecting and quantifying any CO2 surface leakage [§ 98.448]. ● **UIC Class II** defines AoR by either the Theis's analytical equation or a fixed value greater than ¼ mile. ● **UIC Class II** requires: ➢ Well construction designed to inject into a formation separated from any USDW by a confining zone that is free of known open faults or fractures within AoR with cased and cemented (146.22). ➢ Appropriate logs and other tests shall be conducted during the drilling and construction (146.22).	● **Subpart RR** requires the same as on the left. ● **UIC Class VI** requires to define AoR based on computational modeling that accounts for the physical and chemical properties of all phases present [§ 146.84]. ● **UIC Class VI** specify: ➢ Well construction requirements as defined in 146.86, which include the requirements for general well construction, casing and cementing, and tubing and packer [§ 146.86]. ➢ Detailed extensive logging, sampling, and testing requirements prior to injection well operation as defined in [§ 146.87]. ● Under **UIC Class VI**, preparing 3D computational models is compulsory to fulfil the requirements for the delineation of AoR and the risk assessment [§ 146.84].	● Satisfy the following requirements as defined in Directive 065: Containment Assurance, Safety, Well Integrity, Suspension & Abandonment, Reporting. ● In addition to the above, a CO_2-EOR project application should ➢ define the storage capacity estimates and injectivity, ➢ develop models and execute simulations to predict the extent of the CO_2 fluid plume, ➢ predict the behaviour of the hydrocarbon-CO_2 phase, ➢ confirm that the proposed scheme will perform effectively and safely, ➢ establish a site-specific risk assessment that will allow for thorough risk management throughout the life of scheme approval, ➢ establish baseline conditions to design and implement a monitoring program, and ➢ assess the risks associated with storage and remediation strategies in case of loss of ➢ containment.
During-Injection Monitoring	● Use a fluid flow model to periodically compare material balances for fluids as observed and predicted [ACR 5.4.1.3]. ● Undertake a simulation study of potential storage failure scenarios, considering a range of uncertainty for parameters and site characteristics [ACR 5.4.1.3].	Identify monitoring technologies, location, and sampling frequency to enable: 1. Assurance of environmental integrity and safety. 2. Detection and estimation of quantity of CO2 stored in site. 3. Confirmation that injected CO_2 is contained and behaving as predicted. 4. Detection and estimation of the	● **Subpart RR** requires to develop and implement an EPA-approved MRV plan that includes the following five major components [§ 98.448]: 1. Delineation of the maximum monitoring area, and active monitoring areas; 2. Identification of the potential surface leakage pathways and an	● **Subpart RR** requires the same as on the left. ● **UIC Class VI** specifies: ➢ The requirements for operational injection pressure which shall not exceed 90 percent of the fracture pressure of the injection zone(s) [§ 146.88]. ➢ The requirements for mechanical	Conduct monitoring to: ● Demonstrate compliance with legislation (regulations, standards, directives), applications and approvals. ● Monitor for trigger events and, if detected, employ associated operating procedures in response.

	● Perform monitoring for the most sensitive parameters as identified from the above study. Tools selected and sampling frequency must be specified (justified) [5.4.1.3]. ● Select and locate (other) monitoring equipment in a manner that provide confidence in CO_2 storage and identify leakage. Establish reasonable detection thresholds for the equipment [ACR 5.4.1.3]. ● Require the project-specific MRV plan be developed by a professional [ACR 5.4.2].	rate/mass of CO_2 seepage either via cap rock, overburden and surrounding domains or via wells with potential for leakage. 5. Monitoring and measurement of relevant parameters of groundwater properties, soil and surface CO_2 concentrations measurements, etc. 6. Timely remedial action in the event of CO_2 seepage. 7. Measurement of temperature at the top and bottom of injection and observation wells. 8. Detection of corrosion or degradation of transport and injection facilities.	assessment of the likelihood, magnitude, and timing of surface leakage of CO_2 through these pathways; 3. Strategy for detection and quantification of surface leakage; 4. Approach for establishing the expected baselines; and 5. Considerations made to calculate site-specific variables for the mass balance equation. ● **UIC Class II** requires: ➢ Operational injection pressure which shall not exceed a maximum that does not initiate new fractures or propagate existing fractures (146.23). ➢ Monitoring of the nature of injected fluids and observation of injection pressure, flow rate, and cumulative volume at a minimum (146.23).	integrity of wells including the demonstration of the absence of significant leaks through temperature or noise logging at least once per year [§ 146.89]. ➢ The detailed requirements for testing and monitoring in [§ 146.90].	Monitoring technologies are evaluated on a regular basis The MMV plan is periodically renewed and ongoing dialogue is held with the regulator
Post-Injection Monitoring	● **Minimum of 5 years of Post-Injection**. If no migration of the injected CO_2 is detected and the modelled failure scenarios indicate that CO_2 remains contained within the storage volume, then it is considered adequate assurance that no atmospheric leakage has occurred. Otherwise, monitoring requirements will be extended in 2-year increments until no leakage is identified [ACR 5.4.1.4].	● **Minimum of 20 years of Post-Injection**. If no migration of the injected CO_2 is detected and the modelled failure scenarios indicate that CO_2 remains contained within the storage volume, then it is considered adequate assurance that no atmospheric leakage has occurred. Otherwise, monitoring requirements will have to be extended in 10 year increments until no leakage is assured. ● Monitoring is for the same parameters described for "During Injection". ● An evaluation must be performed in the event of seepage to determine the	● **Subpart RR** requires to develop and implement an EPA-approved MRV plan as described above [§ 98.447]. ● **UIC Class II** has **no description on post-injection site care**.	● **Subpart RR** requires the same as on the left. ● **UIC Class VI requires the default value of 50 years of Post-Injection site care.** ➢ The post-injection site care period can be reduced upon showing that "based on monitoring and other site- specific data, that the geologic sequestration project no longer poses an endangerment to USDWs," and the period will be extended if that demonstration cannot be made even at the end of 50 years [§ 146.93].	● the project operator to develop a termination plan for the CO_2-EOR project that specifies criteria for termination. This plan shall be developed any time after CO_2 injection begins, but must be developed prior to the termination of CO_2 injection at the scheme. ● **Regulatory Framework Assessment recommend minimum 10 years**[8] ● Continue to monitor all wells and facilities and perform all closure activities in accordance with the regulations. ● Arrangements are made between the

		quantity of seepage for compensation purposes.		➢ Specific monitoring methods and tools should be site specific and designed for the following objectives: 1) verify plume is stabilizing and pressures are equilibrating and 2) detecting potential leakage [§ 146.93].	regulator and project operator for the transfer of any MMV monitoring equipment that the regulator requests to be left in place at the point of closure that will not compromise long-term integrity of well abandonments.
Reporting/ Accounting	● ACR details the methods and equations to quantify baseline emissions, project emissions, and emission reductions in Equations 4.1 to 4.3 [ACR, 4.1~4.3]. ● Require the project-specific MRV plan be developed by a professional [ACR 5.4.2].	● Determine project boundaries to include an accounting for all GHG emissions as a part of the baseline assessment and monitoring. Verification will be achieved by history matching and, where necessary, updating the numerical models used to characterize the geological storage. The numerical models will be adjusted to address significant deviations between observed and predicted behavior	**Subpart RR** requires facilities to collect quarterly data and submit annual reports on the annual amount of CO_2 sequestered. The mass balance equations RR-11 or RR-12 (EPA, 2010) are used to calculate the amount of CO_2 that is reported as sequestered and accounts for quantity of CO_2 in emissions, the produced gas, the quantity remaining in the oil and gas, and finally the total quantity sequestered	● **Subpart RR** requires the same as on the left.	Documentation requirements for the emission offset project Documentation for the Baseline condition requires Documentation for the Project condition

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