別添 3：CO2-EOR を CO2 削減措置と位置付ける各種制度における技術的要求事項

Appendix 3: Technical requirements defined in different schemes that include CO2-EOR as a means of CO2 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 CO2 enhanced oil recovery in the US in the 45Q Tax Credit[1]; *EPA Class VI plus Subpart RR* is the requirements for CO2 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 after Gupta and Cumming, 2016 [2] with referencing to the original documents for each rules.

	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 entire CCS chain (not just storage), periodically updated to reflect monitoring data. ● Develop remedial measures and response plans to stop or control unintended CO2 emissions or leakage (F. Participation requirement). ● Perform an environmental and socio-economic impact assessment, periodically updated to reflect monitoring data.	● **Subpart RR** requires: ➢ Delineate the maximum monitoring area – the area expected to contain the free phase CO2 plume until injected CO2 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 CO2 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 CO2 fluid plume to assess for and manage risks over the life of the CO2-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 CO2 plume extent and the applied for CO2 EOR storage scheme approval area.

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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 CO2, 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 CO2 via a 3D reservoir model (Appendix B). ● Assess injected CO2 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 strategy for setting monitoring baselines for surface leakage [§ 98.448]. ➢ Define 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 CO2-EOR project application should ➢ define the storage capacity estimates and injectivity, ➢ develop models and execute simulations to predict the extent of the CO2 fluid plume, ➢ predict the behaviour of the hydrocarbon-CO2 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 CO2 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 CO2 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 CO2 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 CO2 concentrations measurements, etc. 6. Timely remedial action in the event of CO2 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 CO2 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 CO2 is detected and the modelled failure scenarios indicate that CO2 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 assured [ACR 5.4.1.4].	● **Minimum of 20 years of Post-Injection**. If no migration of the injected CO2 is detected and the modelled failure scenarios indicate that CO2 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 a 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 CO2-EOR project that specifies criteria for termination. This plan shall be developed any time after CO2 injection begins, but must be developed prior to the termination of CO2 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 CO2 sequestered. The mass balance equations RR-11 or RR-12 (EPA, 2010) are used to calculate the amount of CO2 that is reported as sequestered and accounts for quantity of CO2 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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