Monitoring, measurement, and verification principles and objectives for CO_2 sequestration projects

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Monitoring, Measurement, and Verification Principles and Objectives for CO_2 Sequestration Projects

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MMV Principles and Objectives

What is a Monitoring, Measurement, and Verification Plan?

Monitoring and measurement are surveillance activities necessary for ensuring the safe and reliable operation of a CO_2 sequestration project. Verification refers to the comparison of measured and predicted performance, which is also known as conformance. The purpose of monitoring, measurement, and verification (MMV) is to address health, safety and environmental risks, evaluate sequestration performance and provide evidence that the site is suitable for closure. MMV is central to CO_2 sequestration risk management, and MMV Plans include a Risk Management Plan containing the risk identification, assessment, and management activities specific to the CO_2 sequestration project.

An MMV Plan sets out the monitoring, measurement, verification, and risk management activities that a project proponent will undertake for the term of the evaluation permit/agreement or carbon sequestration lease/agreement. MMV plans are developed by the project operator in response to the risks identified, and to enable regulatory requirements to be met and conditions specified in project approvals to be satisfied.

Sufficient data must be collected regarding the behaviour of the sequestered CO_2 for several purposes. Measurement and monitoring of the injection facilities, geological sequestration site, and surrounding environment provide assurance that CO_2 is confined to the storage complex (i.e., containment). Verification refers to the comparison of measured and predicted performance and is used to ensure sequestration sites are operating as predicted and permitted (i.e., conformance).

What is a Risk Management Plan?

A risk management plan is a scheme specifying the approach, management components, and resources to be applied to the management of risks. For carbon sequestration projects, the risk management plan specifically addresses the risks associated with CO_2 sequestration at a project site.

Risk is the effect of uncertainty on project objectives, expressed in terms of a combination of the severity of consequence of an event and the associated likelihood of their occurrence.

Risk assessment refers to the overall process of risk identification, risk analysis, and risk evaluation associated with CO_2 sequestration at the specified site. Selection of a suitable site requires comprehensive site characterization and risk assessment. A site can be considered suitable if the site characterization and assessment process has demonstrated that the storage of the CO_2 stream at the candidate site does not pose unacceptable risks to other resources, to the environment and human health and safety, and to project developers, owners, operators[1], and the Crown (post closure)

The Risk Management Plan is a fundamental component of the MMV requirement for CCS Projects. Proponents submitting applications for Carbon Sequestration leases are required to submit satisfactory evidence that the site selected is suitable for the purposes of CO_2 sequestration[2]. Alberta Energy recommends that project proponents submit project risk management plans as a separate (stand-alone) appendix within the project's MMV Plan.

Key MMV Principles

- Regulatory compliance
- Project-specific
- Site-specific, but also addresses potential cumulative and regional impacts
- Risk-based
- Fit-for-purpose
- Adaptive, with elaboration through successive project stages
- Provide timely warning of CO_2 stream containment and conformance anomalies in order to take appropriate action

[1] CSA Z741-2012 Geological storage of carbon dioxide

[2] Alberta Regulation 68/2011, S9(9)(2)(d)

- Monitorability in every domain of review (geosphere, hydrosphere, biosphere, and atmosphere)
- Transparency
- Based on sound science and engineering - use best available technologies economically achievable (BATEA)

MMV Objectives

At All Project Stages:

- Meet all regulatory requirements set out in applicable legislation and regulation, and meet the expectations of the Alberta Energy Regulator as described in directives, bulletins, scheme approvals and other sources.
- Demonstrate suitability of the site for the purposes of CO_2 sequestration through a site characterization and risk assessment process conducted in accordance with the CSA Z741-12, its successor or equivalent standard (see the Site Suitability and Risk Assessment Requirements section for further information).
  - Must identify all potential adverse events, assess, and quantify the likelihood and potential consequences of their occurrence, and inform project risk management activities.
  - Particular areas of concern for CO_2 sequestration include assessment of the potential for:
    - Existence of faults, (known/unknown) wells and other zones of weaknesses (e.g., karstic features) that may exist within the area of interest of the storage complex (i.e., the succession of geological and confining formations and their properties (lithology, thickness, extent, and integrity) that contribute to providing secure long-term sequestration of CO_2).
    - Seismicity, both induced and natural.
    - Altering regional groundwater flow/pressure/chemistry regimes.
    - Impacts from CO_2 plume or pressure front on other users of local and regional scale subsurface pore space, including other carbon sequestration operators, oil and gas, minerals, disposal, geothermal, reservoir and salt cavern storage, etc.
    - Affecting non-saline groundwater.
    - Adverse impacts to public in the event of a release event. MMV information will be used to define Emergency Planning Zones and inform Emergency Response Plans, as described in Directive 071: Emergency Preparedness and Response Requirements for the Petroleum Industry.
    - Potential impact of existing and new resource development and other activities on the storage complex.
- Address health, safety, and environmental risks, evaluate sequestration performance and provide evidence for long term safety and security of the storage complex.
  - Potential environmental impacts from CCS operations must be identified in the MMV Plan and addressed through mitigation measures and compliance assurance activities.
  - The storage complex is the succession of geological formations that contribute to providing secure long-term sequestration of CO_2. It may include one or more seals and one or more zones that have the potential to sequester CO_2.
- Protect fresh groundwater systems. Protection of non-saline groundwater
  - As part of ensuring there are no adverse impacts to the environment, a groundwater monitoring program (above the Base of Groundwater Protection (BGWP)) should be developed in collaboration with the Alberta Energy Regulator.
    - This program would establish baseline data for non-saline aquifers, establish that the project will not degrade existing water quality, reduce the risk to the Government of Alberta upon transfer of liability, and help to ensure public and environmental safety.
    - The plan could comprise, but not be limited to, industry monitoring wells and domestic monitoring wells where appropriate.
- Monitor and minimize impacts on adjacent saline groundwater systems and other pore space users, including other CCS, oil and gas, minerals, disposal, geothermal, reservoir and salt cavern storage, etc.
- An induced seismicity hazard assessment, monitoring, and mitigation program must be included as a key component of the MMV Plan.
- Set out the MMV and Risk Management activities that a project proponent/lessee will undertake while the plan is in effect.

During Evaluation Permit/Agreement Application Stage:

During this stage project developers are expected to collect sufficient data to support the site characterization process, which is meant to provide satisfactory evidence of site suitability for the purposes of CO_2 sequestration.

- Analyze the likelihood that operations/activities under the permit/agreement will interfere with other mineral recovery operations
  - This is a key requirement of an MMV plan for an Evaluation Permit, as set out in section 7 of the Carbon Sequestration Tenure Regulation.
- Establish anticipated CO_2 storage resource estimates based on the best available data, prior to conducting the evaluation.
- Establish whether the storage complex is a hydrodynamically open or closed system. Hydrodynamics and spill points must be addressed to support containment assurance in open systems.
- Set out the site characterization activities that will be conducted and how these results will inform the site suitability, project risk, and MMV Plan requirements of the Sequestration Lease application stage.
- Information may include:
  - An overview of how information will be gathered and associated timelines.
  - Plans to assess monitorability.
  - A discussion of the initial risk assessment, as well as plans to undertake a more detailed risk assessment in support of a carbon sequestration lease/agreement application.
  - A legacy well risk assessment that takes into account the selected locations for injection wells and the possible need to upgrade some legacy wells to modern abandonment standards for CO_2 containment.
- Operate in compliance with the plan.
  - Per section 7(2) of the Carbon Sequestration Lease Tenure Regulation, a permittee must not conduct any operations or activities under the evaluation permit unless an MMV plan has been approved in relation to the permit and the permittee complies with the approved plan.

During Sequestration Lease/Agreement Application Stage:

Site Suitability and Risk management Guidance for Sequestration Lease Applications

- Alberta Energy expects that all MMV Plans submitted for sequestration lease/agreement applications, amendments or project updates include a risk management section that is completed in accordance with the requirements of CSA Z741-12, its successor or equivalent standard (e.g., ISO 27914-2017(E), EU Directive 2009/31/EC). This risk management process must be implemented during the initial site screening, selection, and characterization periods, and must be iteratively repeated in a consistent, transparent, and traceable manner throughout the project lifecycle (from site screening/selection up to closure). Comprehensive site characterization, risk assessment and management are fundamental.
- CSA Z741-12 outlines the following required steps in the risk management process:
  1. A site screening, selection, and characterization step to identify suitable candidate sites, consisting of the following elements:
     a) Site elimination, consisting of eliminating sites that lack the technical and legal/regulatory characteristics to be considered suitable for CO_2 storage, including:
        i) unfavorable capacity, injectivity, containment, seismicity, pore pressure, faulting/fracturing, structural deformation, hydrodynamic, monitoring and legacy wellbore characteristics
        ii) within or in communication with protected areas, protected groundwater, natural resources (energy, geothermal, mineral) or restricted pore space rights
     b) Site selection, consisting of assessing:
        i) Subsurface criteria, including capacity, injectivity, storage security, pore space ownership, other subsurface activities, other subsurface resources, and need for pressure control and
        ii) Surface criteria, including access to CO_2 sources, required infrastructure, population density, land ownership and current/future land use, proximity to environmentally sensitive/reserved/protected areas and bodies of water, topography, weather, cultural, historical, socio-economic conditions
     c) Site characterization, consisting of:
        i) Storage unit geological and hydrogeological characterization
        ii) Confining strata, including primary seal and secondary barriers characterization
        iii) Baseline geochemical characterization
        iv) Baseline geomechanical characterization
        v) Legacy wellbore characterization, which takes into account the proposed locations of injection wells and anticipated extent of CO_2 and pressure plume.
     d) Modeling, to understand, predict, and communicate the fate and potential impacts of the injected CO_2 and associated pressure increase over the lifetime of the project including post closure, consisting of:

i) Development of a history matched geologic static model describing key geological, hydrogeological, geothermal and geomechanical features of the storage complex.
ii) Flow modeling of the injected CO_2 flow to predict subsurface movement, assess risks and storage capacity.
iii) sGeochemical modeling to evaluate potential effects of injected CO_2 stream on storage container, primary seal, and wellbore materials.
iv) Geomechanical modeling of the entire storage unit, storage complex and the entire overlying sedimentary succession to evaluate potential effects of stress changes and deformation and associated risks.

2. A risk assessment step, consisting of the following elements.
   a) Identification of elements of concern, including human health, safety, the environment and system performance.
   b) Creation of a conceptual geological static model, which will be used to evaluate the potential behaviour of the storage system. Model must be capable of predicting and describing the performance of the system over time in a manner that provides sufficient technical basis for system risk management.
   c) Identification of context, including the natural environment, regional natural resources, infrastructure and facilities, human culture, legal and regulatory environment, industry best practices and project operators/subcontractors
   d) A risk management plan, including:
      i) Organizational procedures and practices applied to risk management
      ii) A schedule for performing iterative risk assessments and activities supporting the risk assessments
      iii) Principles and guidelines that will be applied to enhance the thoroughness, accuracy, transparency and traceability of risk assessments
      iv) Elements of concern
      v) Project specific risk evaluation criteria for each element of concern aligned with the scope and scale of the project in terms of qualitative versus quantitative likelihoods
      vi) Risk tolerability and acceptance thresholds for each element of concern including how threshold acceptability were determined and communicated with the Alberta Energy Regulator.
      vii) Site specific monitoring plan supporting iterative risk management
      viii) Iterative, adaptive, responsive site-specific modeling and simulation program which accounts for the effects of uncertainties for modelling and simulation results
      ix) An iterative, adaptive project risk register
      x) A schedule and process for updating the risk management plan
   e) Assessment of risks, consisting of:
      i) Risk identification: identification of all scenarios that can carry significant risk.
      ii) Risk analysis: determination of the likelihood and severity of potential consequences for each risk scenario, based on the best available knowledge and scientific reasoning.
      iii) Risk evaluation: determination of the level of tolerability and acceptability of the risk
3. A review and documentation step, consisting of the following elements:
      i) Review and adjustment (update) of the risk management plan and the risk assessment results as necessary throughout the project lifecycle.
      ii) Adequate and consistent documentation of the risk assessment process to ensure transparency and traceability
4. A risk communication and engagement step, consisting of:
      i) Communication and engagement regarding project opportunities and risk with both internal and external parties who may be impacted consistent with the Resource Applications Notification Guidelines contained in Directive 065.

Other Sequestration Lease/Agreement Application MMV Objectives

- Analyze the likelihood that operations/activities under the lease/agreement will interfere with other mineral recovery operations, based on the geological interpretations and calculations the lessee is required to submit to the Alberta Energy Regulator pursuant to Directive 065 (Resources Applications for Oil and Gas Reservoirs) in its application for approval of the injection scheme under the Oil and Gas Conservation Act.
  - This is a key requirement of an MMV plan for a Sequestration Lease, as set out in section 15 of the Carbon Sequestration Tenure Regulation.
- Develop a suitable monitoring plan and schedule
  - Identify monitoring tasks.
  - Screen, evaluate and select monitoring technologies.

- Provide the rationale for selection of monitoring technologies. Selected technologies must be able to detect early warning signs of any unexpected loss of containment. This will be updated if the results of the baseline assessment indicate a need for more-specific monitoring technologies.
- Propose a monitoring schedule.

- Establish appropriate baselines for the selected monitoring technologies
  - Incorporate all monitoring and baseline data requirements identified by the Alberta Energy Regulator during permitting and approval into the MMV plan.
  - Baselines are needed so that anomalous readings for the selected parameter(s) (e.g., pH, CO_2 concentrations) can be identified and response methodologies employed and/or technologies used to provide evidence that the anomalies are not the result of a release from the storage complex.
  - Data must be collected for an appropriate period of time to establish a statistical basis for variations in data.
  - Some of the baseline data may be compiled during site selection through a review of existing data from oil and gas exploration and production activities, or may be newly gathered data.
- Ensure that the monitoring technologies looking at key project risks have the necessary resolution to establish thresholds for action ("trigger events").

During Operation/Injection Stage:

- Operate in compliance with the plan and keep it up to date.
  - Per section 16(1) of the Carbon Sequestration Tenure Regulation, an MMV plan will expire on the earlier of the 3rd anniversary of its approval date or the date that the lease is renewed. A lessee must submit a new MMV plan for approval no fewer than 90 days before its expiry date.
  - Per section 17(1) of the Carbon Sequestration Tenure Regulation, a lessee must not conduct any operations or activities under a carbon sequestration lease unless an MMV has been approved and is in effect for the lease, and the lessee complies with the approved plan.
- 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.
- Compile monitoring results to:
  - Meet the requirement under section 17(2) of the Carbon Sequestration Tenure Regulation to present an annual report to the Minister of Energy on the findings and observations from MMV activities conducted for carbon sequestration lease holders, or as required by the sequestration lease agreement.
  - Inform and update the project Risk Management Plan.
  - Inform and optimize project operations.
  - Trigger investigation of non-conformance and mitigation and/or remediation activities as required.
  - Support the receipt of offset credits.
  - Update simulations and models so actual and predicted behaviour can be compared and the MMV plan can be updated as necessary.
  - Validate model predictive capability throughout the injection period.
- Collect sufficient data needed to:
  - Provide suitable evidence of conformance of CO_2 stream and affected fluids within the storage complex.
  - Provide assurance of geological containment of CO_2 stream and affected fluids within the storage complex.
  - Provide suitable evidence of no significant adverse effects to other pore space users within hydraulically connected saline formations.
  - Provide suitable evidence that there are no significant adverse effects of CO_2 injection on health, the environment or other resources.
  - Provide suitable evidence of the amount of CO_2 sequestered and to support permanent reduction of greenhouse gases as described in the Quantification Protocol for the Capture of CO_2 and Storage in Deep Saline Aquifers.
  - Verify and update models and simulations annually, and use the results to continually inform capacity estimates and conformance verification.
- Monitor threats to containment identified in the project risk assessment and where loss of containment is confirmed, trigger appropriate mitigation and/or remediation activities.

- Monitoring technologies are evaluated on a regular basis to:
  - Ensure effectiveness of each technology for the designated task as compared to expectations in the MMV plan.
  - Ensure overlapping technologies are complementary and provide the spectrum of results needed to evaluate sequestration performance.
  - Evaluate technologies in use against advancements so new monitoring techniques are deployed when warranted.
- The MMV plan is periodically renewed and ongoing dialogue is held with the Alberta Energy Regulator to ensure:
  - Time-sensitive data are collected when available and to the extent required.
  - Simulations and models incorporate actual results to allow comparison of actual and predicted behaviour, and evolve as required to illustrate sequestration performance at closure.

During Closure Period Stage:

- Operate in compliance with the plan and keep it up to date (the following apply to the Sequestration Lease MMV plan)
  - Per section 16(1) of the Carbon Sequestration Tenure Regulation, an MMV plan will expire on the earlier of the 3rd anniversary of its approval date or the date that the lease is renewed. A lessee must submit a new MMV plan for approval no fewer than 90 days before its expiry date.
  - Per section 17(1) of the Carbon Sequestration Tenure Regulation, a lessee must not conduct any operations or activities under a carbon sequestration lease unless a Carbon Sequestration Lease MMV has been approved and is in effect for the lease, and the lessee complies with the approved plan.
- Continue to monitor all wells and facilities and perform all closure activities in accordance with the regulations.
  - Selected monitoring activities continue to demonstrate sequestration performance and compliance with legislation (e.g., regulations, standards, directives), applications, and approvals.
  - This includes demonstrating compliance with section 119 of the Mines and Minerals Act, abandonment of all wells and facilities in accordance with the requirements under the Oil and Gas Conservation Act and under Part 9 of the Mines and Minerals Act, compliance with the reclamation requirements under the Environmental Protection and Enhancement Act, showing that the closure period specified in the regulations has passed, and that the conditions specified in the regulations have been met.
  - Provide evidence to support the issuance of a closure certificate (i.e., meet the requirements of section 120(3) of the Mines and Minerals Act, including providing evidence that the captured carbon dioxide is behaving in a stable and predictable manner, with no significant risk of future leakage out of the storage complex).
- Collect sufficient data needed to:
  - Provide evidence of conformance of CO_2 stream and affected fluids within the storage complex.
  - Provide assurance of geological containment of CO_2 stream and affected fluids within the storage complex.
  - Provide evidence of no significant adverse effects to other pore space users within hydraulically connected saline formations.
  - Provide evidence that there are no significant adverse effects of CO_2 injection on health, the environment or other resources.
  - Provide evidence of the amount of CO_2 sequestered and to support permanent reduction of greenhouse gases as described in the Quantification Protocol for the Capture of CO_2 and Storage in Deep Saline Aquifers.
- Verify and update models and simulations annually and use the results to continually inform capacity estimates and conformance verification.
- Monitor threats to containment identified in the project risk assessment and where loss of containment is confirmed, trigger appropriate mitigation and/or remediation activities.
- Provide information to the Alberta Energy Regulator when requested regarding appropriate MMV techniques that could be used in the post-closure period.
- Arrangements are made between the Alberta Energy 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.

Additional Monitoring, Measurement, and Verification Resources

For more information on MMV plans, please refer to the following documents:

Alberta Department of Energy, 2013, Carbon Capture & Storage: Summary Report of the Regulatory Framework Assessment. https://open.alberta.ca/dataset/9781460105641/resource/ecab392b-4757-4351-a157-9d5aebededecd0

U.S. Department of Energy, 2017, Best practices—monitoring, verification, and accounting (MVA) for geologic storage projects: 2017 Revised Edition, DOE/NETL-2017/1847. https://www.netl.doe.gov/sites/default/files/2018-10/BPM-MVA-2012.pdf

Plains CO_2 Reduction (PCOR) Partnership, 2018, Best Practices Manual – Monitoring for CO_2 Storage. https://undeerc.org/pcor/assets/PDFs/PCOR-BPM-Monitoring-for-CO2-Storage.pdf

Canadian Standards Association, 2012, CSA Group Z741-12 Geologic storage of carbon dioxide: Mississauga, Ontario, October.

International Organization for Standardization, 2017, ISO 27914 Carbon dioxide capture, transportation and geological storage — Geological storage.