# The Role of Geophysics in the Reduction of Risk and Uncertainty for CCS Projects

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Since 2020, there has been a resurgence in interest in carbon capture and storage (CCS) projects in North America and around the world. While many aspects of CCS projects are similar to traditional oil and gas projects, CCS projects also present unique challenges and uncertainties in terms of economics, site characterization, measurement, monitoring, and verification (MMV), site closure, and public assurance. A variety of geophysical tools can be used to reduce project uncertainties before, during, and after the operational life of these projects.

Much of the potential storage capacity in Canada and the United States lies within deep saline formations for which sparse geologic and geophysical information exists. For some projects, the closest well data may be over 50 kilometres away thus leading to considerable uncertainty for geologic characterization including construction of the initial static and dynamic models. In addition, project economics and technical risks related to containment will minimize the number of project wells that penetrate the primary confining zone in the storage complex. Therefore, it is of critical importance to design the pre-injection, or baseline, data acquisition strategy to ensure that it is suitable for monitoring during the operational and post-injection phases of the project life cycle.

Baseline three-dimensional (3D) surface seismic surveys should be designed and planned with multiple short and long-term objectives in mind:

- Reduction of uncertainties such as the depths, thickness and lateral continuity of storage units and seals comprising the storage complex,
- Structural or stratigraphic features that may pose a risk to long-term containment and control $CO_2$ or pressure plume development,
- Characterization of rock properties away from the project wells,
- Identification of features that may serve as focal points for induced seismicity,
- Coverage of the potential footprint of the $CO_2$ plume over the life of the project, and
- Serve as a baseline dataset for comparison to future time-lapse surveys.

High resolution 3D surface seismic data should be processed through to inversion for rock properties, such as porosity and lithology, in order to characterize heterogeneities in the storage formation that control $CO_2$ plume development. Ideally, the inversion will be calibrated using rock properties from well logs and core analysis from project wells. The property cubes derived from the seismic data will be used to update the static model and better constrain the dynamic modelling thereby resulting in more accurate predictions of the evolution of $CO_2$ and pressure plumes. This workflow will enable a project to demonstrate conformance between the project models and the MMV data acquired during operations that ultimately will be required to obtain site closure post-injection.

Given the economics of CCS projects, operators will be looking for alternate MMV technologies that will allow a project to increase the time between more costly full time-lapse surface seismic surveys. Alternate imaging options include:

- Time-lapse vertical seismic profile (VSP) surveys acquired with distributed acoustic sensor (DAS) fibre
- Permanent surface-based DAS installations
- Targeted monitoring of specific areas using sparse permanent arrays

Time-lapse VSP surveys acquired through DAS fibre permanently installed project wells could be used to image early development of the $CO_2$ plume. This data acquisition strategy would also be useful to monitor for potential vertical leakage out of the storage complex. The viability of this approach would need to be evaluated on a case-by-case basis depending on the proposed injection volumes and potential imaging aperture of the VSP array. The feasibility of permanently installed surface-based DAS fibre will be highly dependent on the land use around a project site.

There is currently a great deal of research and effort being put into the development of sparse seismic monitoring technologies that can be used to monitor specific areas within the project site. The advantages of these approaches include the installation of dual-purpose stations that can also be used for induced seismicity monitoring and that have lower impact on surrounding landowners. The deployment of these types of monitoring strategies is still largely untested in large, long-term commercial $CO_2$ storage projects.

Finally, the possibility of induced seismicity and the generation of felt seismic events are of concern to regulatory bodies and the general public. While injection pressures are limited to 80% to 90% of storage formation fracture pressure in most jurisdictions in order to significantly reduce the potential for induced fracturing in the storage complex, it does not eliminate the potential for generation of induced seismicity for a project. Geophysical methods for induced seismicity monitoring are critical for CCS projects to ensure safe operations. The development and design of induced seismicity monitoring methods has been refined through the development of unconventional hydrocarbon resources and tracking of hydrofracturing activities. The application of these techniques for monitoring of CCS sites will serve to increase the confidence of regulatory bodies and the general public in these projects.

Geophysical data and monitoring are significant components of all phases of a CCS project including the development, operation, and post-injection phases. The planning and design of these methods are key for operational guidance, reporting to regulatory agencies and, importantly, informing stakeholders about the safe execution and performance of commercial CCS projects.