Distributed Fibre Optic Monitoring for CCS with Carina® CarbonSecure™

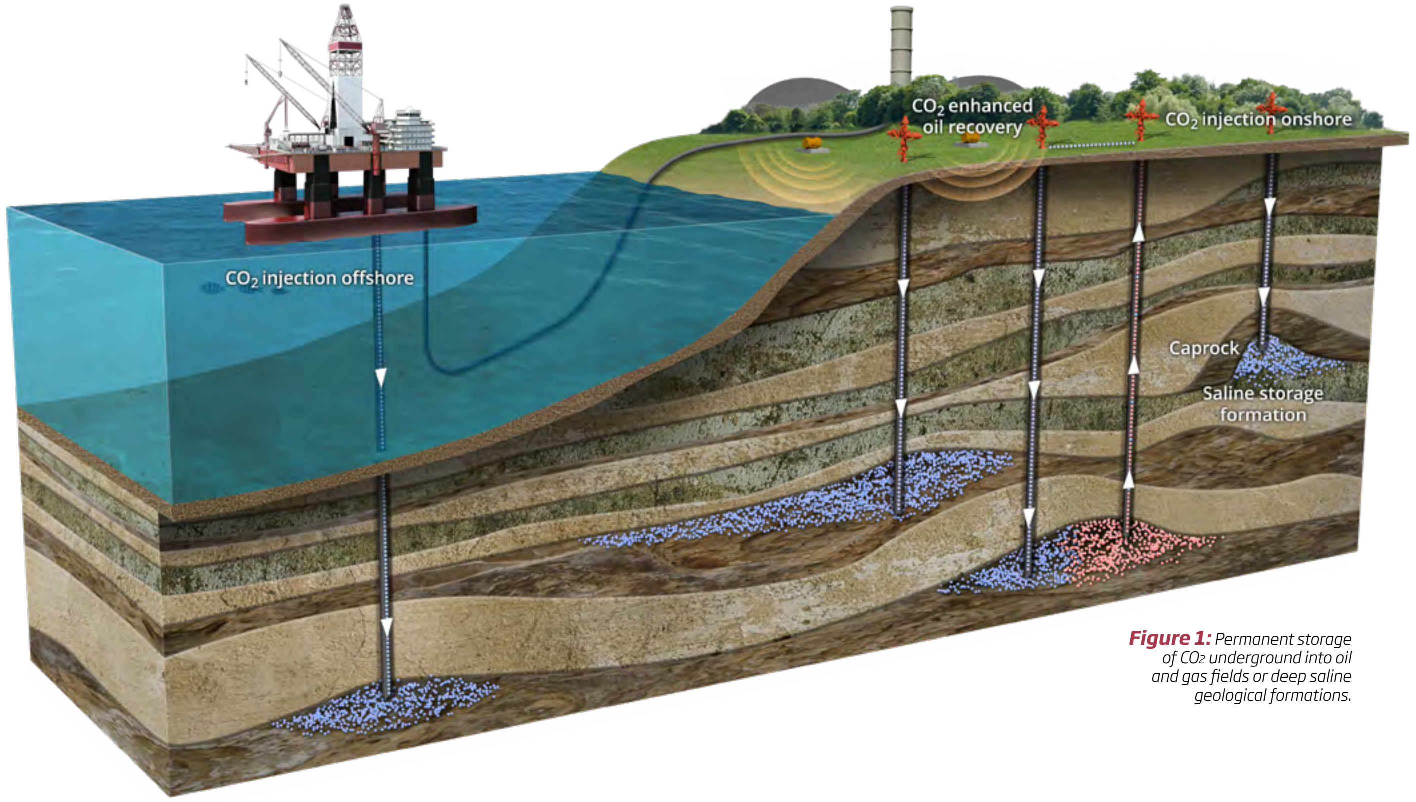

Figure 1: *Permanent storage of CO_2 underground into oil and gas fields or deep saline geological formations.*

MICHAEL MONDANOS, GARTH NALDRETT, PETER SMITH, JESS KOZMAN, PIERPAOLO MARCHESINI, ANNA STORK

INTRODUCTION

Carbon Capture and Storage (CCS) technology offers an opportunity to reduce the concentration of CO_2 in the atmosphere. Typically, CO_2 is injected underground into depleted oil and gas fields, coalbeds or deep saline geological formations, where it is securely stored (Figure 1). For a formation to be suitable for CO_2 storage three main requirements need to be fulfilled; capacity, injectivity and containment. During injection and after the closure of the storage formation, the stored CO_2 and the decommissioned injection infrastructure should be monitored for the following reasons:

- Conformance monitoring: ensuring the operator of the field understands the movement and migration of CO_2.
- Containment monitoring: ensuring and monitoring that injected CO_2 remains within the storage formation.
- Contingency monitoring: monitoring to ensure that the contingency measures designed to stop movement of CO_2 out of the storage formation are still functioning.

Regulatory frameworks governing geological CO_2 storage are being developed worldwide. A series of monitoring requirements exists during operation for CO_2 injection. These requirements focus on mitigating risks arising from the injection of large volumes of CO_2 under high pressure in deep reservoirs. The evaluation of storage performance and containment is captured under a Measurement, Monitoring and Verification (MMV) framework.

DISTRIBUTED FIBRE OPTIC SENSING

Fibre optic distributed sensing methods focus on near surface and subsurface monitoring. They can greatly advance the spatial and temporal resolution of the data acquired during the characterisation and monitoring phases, while reducing overall monitoring costs when compared to standard methods which use point transducers such as geophones, temperature and pressure gauges.

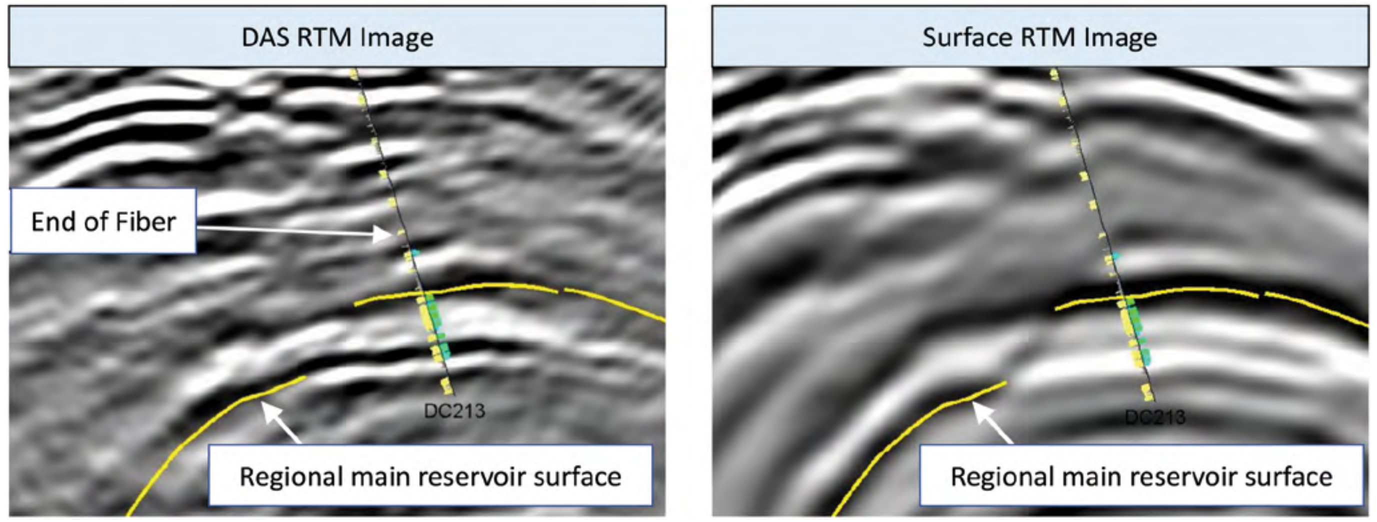

Figure 2: *Comparison of deepwater subsea DAS RTM image (left) with Surface RTM (right).*

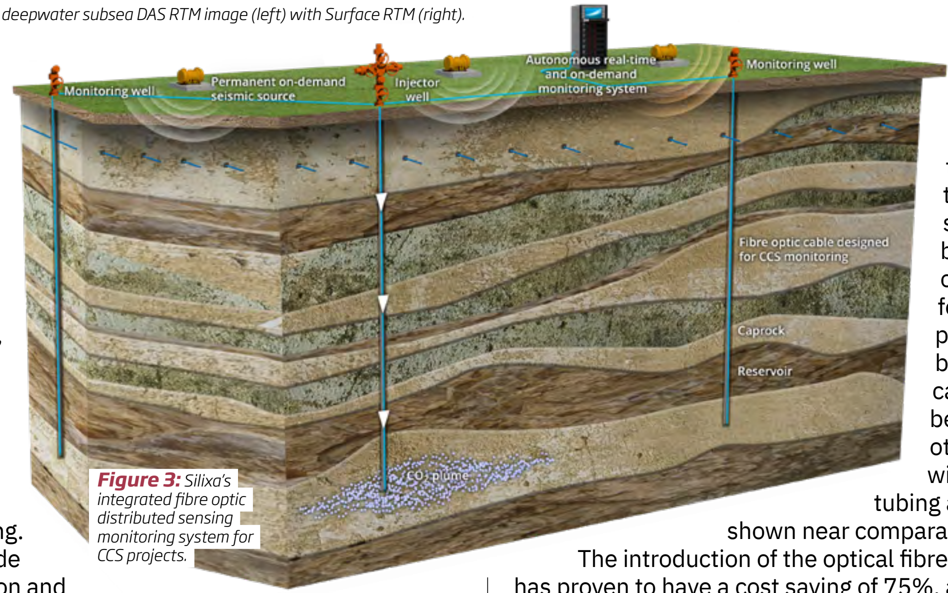

Figure 3: *Silixa's integrated fibre optic distributed sensing monitoring system for CCS projects.*

Fibre-optic cables can be used at all stages of a CCS project, to build a temperature, strain and seismic baseline for site characterisation, monitoring of injection activities, and finally, due to the long-life expectancy of the fibres, the same system can be used for post-injection monitoring. Applications include site characterisation and plume monitoring with Vertical Seismic Profiling (VSP) surveys (e.g., Pevner et al. 2021; White et al., 2019); microseismic monitoring for natural baseline and induced seismic activity (e.g., Stork et al., 2022) and temperature monitoring for well integrity applications (e.g., Ricard, 2020).

The characterisation, evaluation and monitoring of geological storage sites is based on techniques largely adopted from the oil and gas industry. It is essential to address and establish the technical feasibility of the CO_2 storage site based on the capacity to store the volume required as well as the ability to retain all injected and displaced fluid. Subsurface characterisation is directed toward reducing the uncertainty associated with these general constraints. Well design and instrumentation must consider their broad function to support a MMV program identified for a particular site according to the regulatory requirements.

One of the first autonomous systems for CO_2 storage monitoring was implemented at the CO2CRC Otway Project in Australia, and the preliminary results have been published by Isaenkov et al. (2021). The authors highlighted that the "monitoring system allows acquisition of seismic vintages every two days in an automated manner. The permanent installation requires no human effort on-site and thus drastically reduces the monitoring cost. Such a system can coexist within industrial or farm area as it produces a tolerable level of noise and operates only within the allowed time schedule (in the daytime)". The system deployed has been in continuous operation the last few years. The best performance has been achieved with cables installed behind casing but other installations with the fibre optic on tubing and suspended have shown near comparable performance.

The introduction of the optical fibre monitoring system has proven to have a cost saving of 75%, and substantial reduction of CO_2 emissions, over traditional monitoring technologies.

A significant amount of future CO_2 injection is likely to take place offshore where large high-quality CO_2 storage resources exist. In addition to the cost and emissions reduction mentioned above a further benefit of permanent monitoring is the reduction in offshore personnel. While several offshore production platforms have the Carina® monitoring system installed the monitoring of subsea wells has only recently become feasible through the introduction of the Carina® Subsea 4D system. By using an engineered Constellation™ fibre with high optical scattering in the subsea well the interrogator can be located onshore, or on a host FPSO or platform, and connected to the subsea well via standard umbilicals. Operating through standard single mode fibres and ROV wet mate connectors in the umbilical few modifications and no customisation is required. Reliability is also ensured by using qualified, field-proven technologies. As the interrogator is located on the host facility it reduces installation costs, simplifies data transfer, allows system upgrades over the installed life, improves reliability, and reduces power and communication interface requirements within the subsea production system.

The Carina Subsea 4D system won the "Best Deepwater Technology" award from World Oil and has since successfully been installed in several deepwater wells in the Gulf of Mexico, as well as the North Sea. In February 2023 BP presented the results of their first deepwater DAS 3D seismic acquisition, showing a significant enhancement in frequency content and resolution at the target and better ties to the well log, compared to the surface seismic (Figure 2). In the context of CO_2 injection this improvement would allow for higher resolution timelapse imaging of the CO_2 plume.

CARINA CARBON SECURE

Silixa's Carina CarbonSecure is a permanently installed, proven distributed sensing-based solution that allows a step change in the reduction of cost of CCS monitoring, throughout the lifetime of the project. With minimal environmental impact, the system provides a reliable continuous or on-demand monitoring solution for all stages of any CO_2 storage operation, both offshore and on land. It ensures maximum safety over the various stages of the CCS process, and also long-term monitoring and management of the CO_2 storage reservoir while offering significant cost savings. Apart from the numerous operational benefits, the system also has the potential to facilitate faster CCS adoption in industry.

The underlying technology, the Carina® Sensing System, with its market leading performance of 20dB (100 times) improvement in signal-to-noise ratio, delivers high-resolution measurements with unique levels of detail and full wellbore coverage throughout the lifetime of a CCS project. This is obtained using the precision engineered Constellation fibre. Given the system's extreme sensitivity, active seismic surveys can be efficiently conducted with smaller seismic sources providing early warning of potential CO_2 leakage pathways, ensuring maximum safety at the site, minimal environmental impact, and reducing operational time and costs. Using the same fibre optic cable, continuous and real-time microseismic monitoring delivers a more detailed picture of seismicity than traditional technologies to mitigate potential seismic hazards. Wellbore integrity and plume breakthrough can also be monitored using Silixa's ULTIMA™ DTS and XT-DTS™, and Distributed Strain Sensing (iDSS™) systems on the same fibre optic cable installation.

The system can be fully automated, offering on-demand or continuous remote monitoring. The system is compatible with permanent noise sources located at fixed positions. As the fibre is the sensor, there is minimum maintenance requirement.

Real-time data processing is conducted on an Edge architecture to maximize the in-situ processing power and operational flexibility. The approach allows for remote and efficient QC/QA, data analysis, and multi-physics data integration and avoids high bandwidth requirements for offsite data transmission.

The Distributed Acoustic, Temperature and Strain interrogators can be activated at specific times to record for specified periods. When acquisition is performed without continuous supervision, a log of performance metrics (Key Performance Indicators, KPIs) is kept and displayed. Advanced functionality includes alarms and notifications by email if necessary.

Processing requirements are determined by the applications developed for the specific site. The processing modules are grouped in nodes to process data received from the relevant interrogator units. If a unit is used for multiple operations, then it must be configured to accommodate different set up parameters under a scheduler operation. Potentially, there may be different acquisition settings for a single interrogator depending on the applications.

RESULTS

Figure 4 shows an example of time-lapse VSP dataset (baseline & difference surveys) from Otway, Australia. A fully automated system with permanent seismic source and fibre cables behind casing in multiple wells is used to track and monitor the evolution of the injected CO_2 plume (Pevzner et al., 2021). Figure 5 shows top-view seismic images from a 4D dataset monitoring the growth of the CO_2 plume from Aquistore site, Canada. The seismic amplitude anomalies are associated with a ~5m thick zone of injected CO_2 (White et al., 2019). The relationship between seismic velocities and CO_2 saturation can be calculated by monitoring the reflectivity changes in amplitude above the target reservoir and the travel time delays within and below the injection interval (Al Hosni et al., 2016).

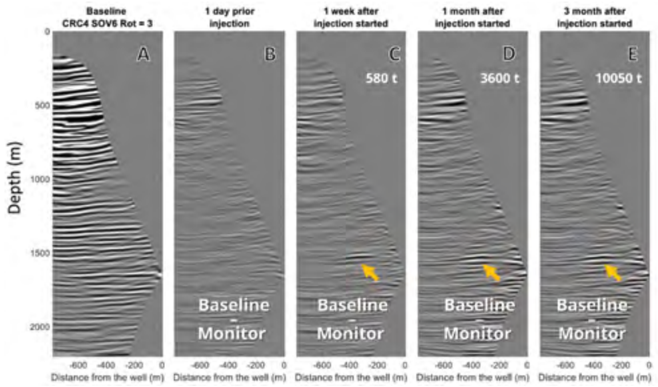

Figure 4: Otway, Australia On-demand time-lapse VSP for plume tracking using permanent sources (Pevzner et al., 2021).

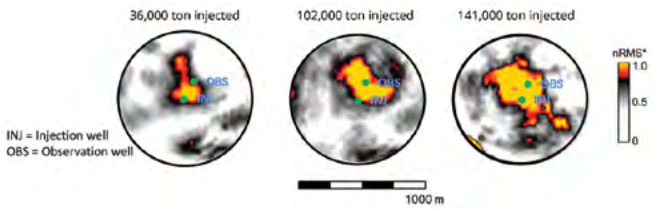

Figure 5: Aquistore Canada, 4D VSP surveys for plume monitoring (White et al., 2019).

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