Carbon capture and storage:

Release of CO_2/formation waters from primary storage reservoirs through geological formations/discontinuities

The SECURe project employed the Bow Tie risk assessment approach, which identifies a series of barriers that prevent a principal hazard ("top event") from occurring. This factsheet outlines recommendations, which address a single top event that can occur if control of a hazard is lost: the release of carbon dioxide (CO_2)/formation waters from the storage complex through geological formations/discontinuities. It should be read in conjunction with the Participatory Monitoring Factsheet, which provides overall guidance on project construction.

The issue

Although very unlikely and considered to be of lower risk than release via wells, the potential release of CO_2 or formation waters from primary storage reservoirs must be fully assessed. Such releases could result in CO_2 emissions to the atmosphere, releases to the seabed and seawater, and/or impacts to ecosystems and people, including other subsurface users. Potential release mechanisms have been identified via existing or legacy wells, via gas chimneys, capillary leakage through the primary seal, via fracture and fault networks or via lateral migration during or after injection. Faults may be reactivated and new fractures induced from stresses during injection or during natural seismicity.

Effective barriers to prevent CO_2 release are provided by a range of site engineering, operational strategies, and corrective actions and by monitoring site selection. These ensure stores will be inherently "safe by design". If release were to occur, then remediation options include monitoring, operational responses, well engineering interventions, and the use of natural geological properties to slow the release. These barriers, as well as preventive and remedial actions, are discussed in detail in SECURe report BGS-01-R-12.

CLICK HERE FOR FULL GOOD PRACTICE REPORT

This report is part of a project that has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement number 764531. The content of this report reflects only the authors' view. The Innovation and Networks Executive Agency (INEA) is not responsible for any use that may be made of the information it contains.

For more information about the project, contact info@securegeoenergy.eu

Risk mitigation recommendations

Maintaining borehole integrity

- Operators should use **cement formulations that minimise shrinkage**, when possible. Cement shrinkage can significantly increase the probability of failure for the shale gas well. Appropriate cement properties and operating conditions can be selected to reduce well failures risks by using the modelling and relationships demonstrated in D2.6. Cement formulations that lead to a softer, more flexible (i.e. more ductile) cement are recommended.
- Microannuli, or small gaps, along the well, and radial fractures emanating from the casing through the cement should be considered in **leakage mitigation strategies**. Individual fractures may dramatically increase the leakage risk, but fracture networks do not necessarily lead to a continuous, high-permeability path along the wells. (D2.6).
- **Reducing the temperature shock of the cold CO_2** is the most effective way to reduce cement failure risks (D2.6).
- **We recommend the use of the more readily available and more widely accepted Portland cement for remediation treatments**, where the strategy is to have a single slurry capable of curing in the cement sheath and in low-permeability fractures (D5.4). Although guidelines for remediation treatments have not been defined by SECURe, we have established several test methodologies, which we think satisfactorily represent more diverse and more realistic field situations.

Monitoring approach

- **Thresholds should be set** for hydrochemical parameters that could indicate contamination in the future (D3.6). Thresholds should be established using the environmental baseline data to calculate concentrations of parameters that would indicate excessive natural temporal variation.
- **Hydrochemical parameters to be used as indicators of contamination should be selected** based on the mineralogy of the aquifer, the characteristics of the potential contaminant (for example, CO_2/formation water release), and the nature of any likely reaction between the two (for example, decreased pH) (D3.6).
- There might be limited baseline data describing the natural environmental condition in terms of scope and resolution in areas of prior development, as highlighted in D3.7. Thus, there might be insufficient information on the reference level for observed changes, which means that **interdisciplinary observations comparisons and extensive modelling** are required to properly assess both subsurface processes and environmental impact.
- There is a strong need for **close cooperation of industry and researchers** in planning and conducting both baseline studies and further monitoring activities (as recommended in D3.7 and D3.8). The possibility of connecting observation results with an industrial process is crucial for the interpretation of phenomena observed in the environment. Results obtained from all observation systems should be reported both to the site operator and to controlling bodies. This would ensure that any adverse changes and causes are identified and appropriate actions undertaken in order to minimise any impact and further risk.
- Long-term **monitoring microseismic events may be an appropriate early warning tool** if such events indicate fluid migration along existing or artificial faults and fractures (see D3.8).
- Long-term environmental monitoring needs to be established for both the operation and post-operation phases (the question is for how long; for now, we can say that it must be set according to specific site conditions). D3.8 recommends that such **monitoring needs to have clearly defined financing and should be conducted by an independent body/bodies. It should be carried out in cooperation with the industry** but not under industry's supervision, to ensure impartiality.

Risk mitigation recommendations (cont.)

Use of models

- **We recommend a multi-disciplinary approach to assess fault leakage rates**, requiring suitable field work, laboratory work and upscaled hydromechanical modelling (D2.6). This might require involvement of analogue sites to access suitable sample material and geological outcrops.
- When it does occur, **leakage can be considered a long-lasting process** due to the large volumes of CO_2 injected, with sustained high gas pressures in carbon stores (D2.6). Storage strategies should be designed to acknowledge this.
- Geomechanical models should be **calibrated by detailed data of geomechanical rock properties** of the structure and its surroundings (D2.6).
- **Reliable datasets (e.g. seismic and wireline-logging datasets) of sufficient quality and quantity** should contribute to fault sealing models (D2.6).
- Calibrate **accurate thresholds for determining reliable outcomes for the Shale Gouge Ratio** (SGR), which can indicate fault sealing potential (D2.6). To determine these thresholds, all available geological information should be used; it is worth noting that application to rock types other than sedimentary clastic rocks can be unreliable.
- **Quantification of top seals**: seals higher in clay are typically lower in matrix permeability and more ductile with lower permeabilities through discontinuities, such as faults and fractures; these limit vertical CO_2 migration through lower expected flow rates in geological storage operations (D2.6). Many ductile caprocks can be considered self-sealing for fault/fracture flow, especially under the changes in effective stresses considered in CO_2 storage operations. Acquisition of extended data from dedicated monitoring wells and their subsequent usage should be used to **history match and validate the simulation model (**D2.6**)**.
- Independent means to estimate the key subsurface pressure parameters (formation breakdown pressure, threshold displacement pressure) of the potential leakage pathways should be used to **validate pressure management and injection strategies (**D2.6**)**.

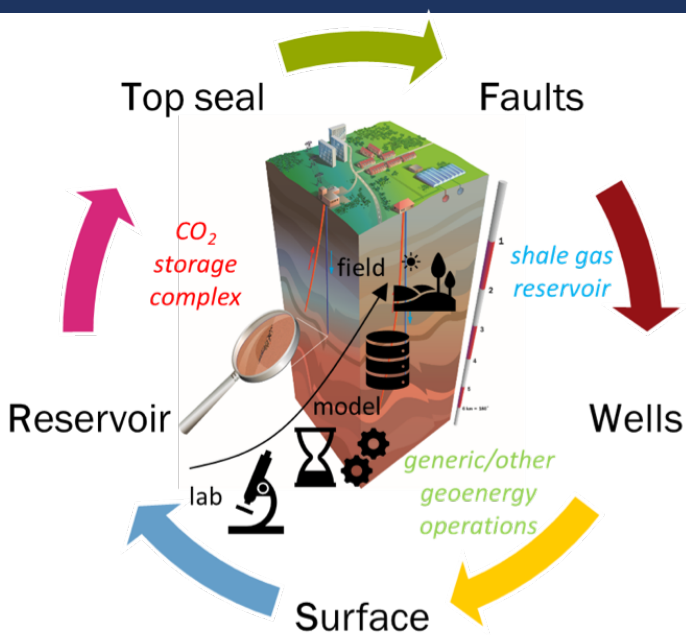

Figure 1: Application domains (CO_2 storage complex, shale gas reservoir and generic/other geoenergy operations), Topics or impact areas/risk receptor (R-Reservoir, T-Top seal, F-Faults, W-Wells, S-Surface), and tools or methods (lab experiments, modelling, field cases - as indicated by symbols and text in figure) for research within WP2 of the SECURe project (from D2.6).

Risk mitigation recommendations (cont.)

Development of technology

- **Technology development** both in monitoring measurements and in interpretation of results should be foreseen. All changes in monitoring scope and schedule should be introduced gradually and in parallel to ensure new and former results are comparable, if not directly, by means of recounting techniques (D3.8).
- Data collected with unmanned aerial vehicle (UAV) based systems can be combined with modelling to localise the source of the emissions on the ground (D4.1). This approach helps to focus ground investigations to pinpoint the gas source and to determine the flux in a tiered monitoring programme. Field tests (D4.1) of the fixed wing UAV and rotary drone UAV gas sensor systems **are capable of monitoring and recording atmospheric gas concentrations in flight**. Whilst they can record positional data and detect gas from surface emissions, further development is required before their application in monitoring programmes.
- The precipitation of **acid-resistant carbonate minerals** through chemical interaction between injected fluids and leaking CO_2 **can act as an effective sealant for remediating CO_2 leakage through faults and fractures in geologic CO_2 storage reservoirs.** This is the case when such precipitating fluids can be directed to leaking faults and fractures (D5.8). Magnesite is one of the most stable carbonate phases that can help address the challenge of long-term plugging of CO_2 leakage. The chemical mechanism that can catalyse its formation is of great interest and practical significance.

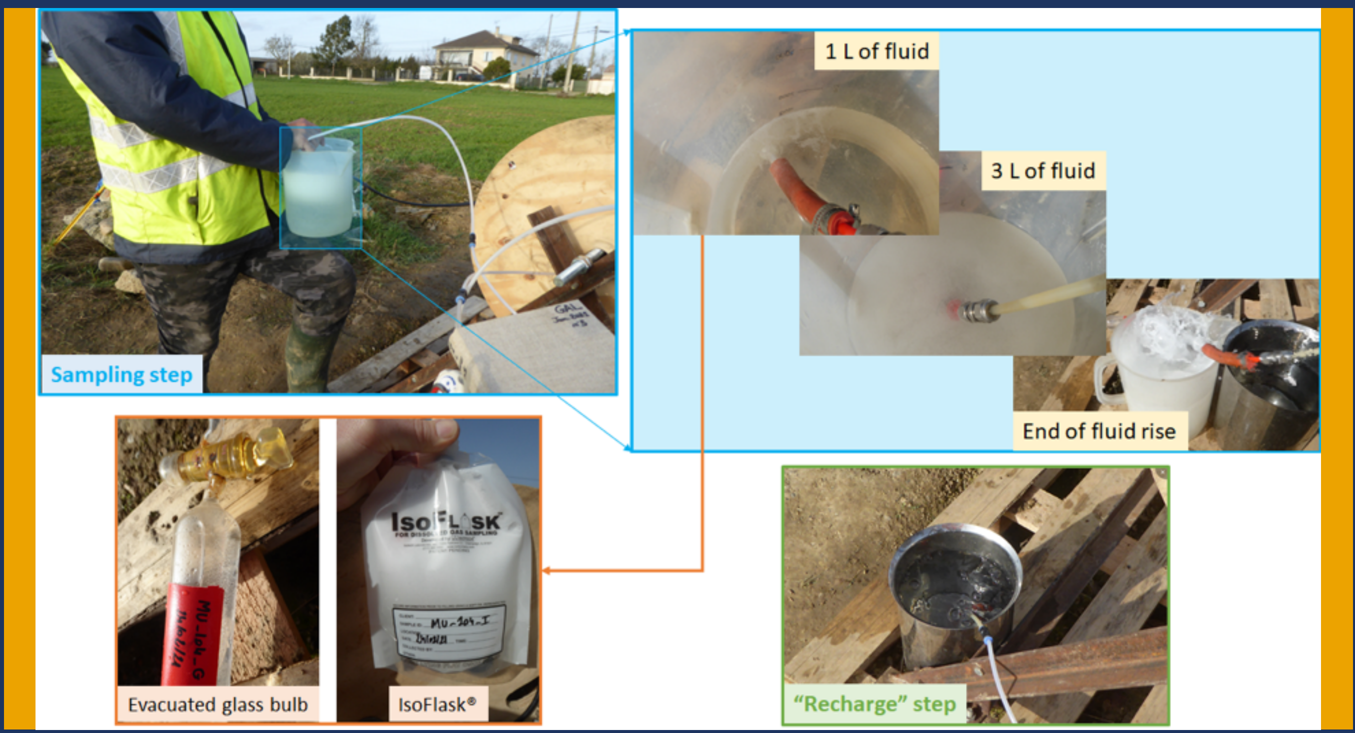

Figure 2: Samples collected from a deep aquifer using the BRGM GazOGaz sampling system (a tool deployed via boreholes). Samples may be collected for chemical analysis (images on the left) and an evaluation of the aquifer water renewal rate may be performed (images on the right).