WP3 summary; Fate of CO_2 entering the water-column.

Purpose

This is a brief report on activities and findings in WP3, whose scope has been to assess the fate of CO_2 released at the seafloor.

Contributing partners in WP3:

- University of Bergen (lead)
- Geomar
- Heriot-Watt University
- University of Rome
- NIVA
- Uni Research
- MPI
- NOCS
- OGS

Background

-The *EU directive 2009/31/EC* establishes a legal framework for geological storage, eliminating as far as possible negative effects and environmental risks associated with geological storage operations, aligned with the amendments to the 1996 *London Protocol* and to the *OSPAR Convention*.
- *Annex I* of the directive specifies criteria for characterization and assessment of storage sites, which includes ***exposure*** assessment, based on characteristics of the environment and the "*potential behaviour and fate of the leaking CO_2"*. This assessment will lay the foundation for latter required ***effects*** assessments ("*at a range of temporal and spatial scales"*) and ***risk*** characterisations (worst case environmental impact and identify sources and reduction of uncertainties).
- *Annex II* in the directive specifies criteria for establishing and updating a monitoring plan using best available technologies and use of "*technologies that can detect presence, location and migration paths of CO_2 in the subsurface and at surface"* should be considered. Further, technologies that can provide a wide areal spread to capture information on any previously undetected leakage pathways and detect significant irregularities or migration of CO_2.
-The monitoring plan shall be updated at least every five years *"to take account of changes to the assessed risk of leakage, changes to the assessed risks to the environment and human health, new scientific knowledge, and improvements in best available technology*".
- The cornerstone for exposure assessments and the possibility of detecting a CO_2 leak to the marine environment is the spatial extent of the CO_2 signal in a varying marine environment, the ***footprint*** of a leak, governed by a number of biogeohemical and physical processes. In addition, instruments, their capabilities and uncertainties, will determine our ability to assure detection of a leak to marine waters.

Achievements:

- ECO2 has had an extensive **cruise program**, during which characteristics of bubble dynamics, near-field plume, and the evolution of dissolved constituents under the influence of local hydrodynamics have been studied at natural leakage sites and during a CO_2 **release experiment** performed in the North Sea. The studies indicate that the impact of CO_2 seepage is primarily limited to bottom water and will be very localized. *See D3.1.*
- The marine environment is hostile to instruments. ECO2 WP3 has reviewed available **chemical sensors**, emphasizing the challenges of long-term deployment including drift related to for example biofouling. Some newly developed tools taking into consideration the full biogeochemical changes in the water column do show potential for autonomous continuous monitoring, and approaches to account for the natural variability have been suggested. *See D3.2 for details*.
-**Acoustic methods** have been assessed. It was demonstrated that multibeam echo sounders (*MBES*) have the potential to provide fast and affordable surveys, with high

resolution, to detect gas seeps. The concurrent acquisition of bathymetric data offers a detailed look at seafloor features that may be related to the gas seeps. Single-beam echo sounders (*SBES*) are appropriate for gathering time-series at a single location. *See D3.1*.
- The four **numerical models** used; a marine chemistry model (scale: 10^{-2} m), two different near-field two-phase plume models (scales: m to km), and a regional scale general circulation model (scale: km) have used data from the ECO2 cruise program (and other sources), to tune and to better estimate sub-model parameters. This has produced more reliable model formulations as a result. *See D3.1 for details.*
- A number of **leak scenarios** have been simulated as part of the overall scenarios as defined under the CCT2 umbrella. A WP3 objective has been to estimate the spatial footprint of a leak, including level of acidification. The likelihood of the different scenarios to occur has been addressed in WP1 and WP2, while subsequent environmental impact assessments are the scope of WP4. *See D3.4 for report on the scenarios.*
-Even though the models used in this study are very different; they all support the field campaign observation that the distinct footprint of a leak will be very localized. The flux, topology of the leak (dispersed small leaks vs. single point large flux), and bubble size distribution at the seafloor influences the maximum concentration and spatial extent of the footprint. This emphasise the need for proper and reliable predictions on how the CO_2 reaches the seafloor.
-Transport and dilution of dissolved CO_2 is highly dependent on local stratification, current and mixing conditions. The varying current direction (e.g. tide) also determines the movement of the dissolved CO_2 plume. Even though the average signal may be very low at a location, spots of higher concentration may pass sporadically making detection possible given appropriate continuous monitoring systems.

Key Considerations

-The limited spatial footprint of a leak suggests that a distinct signal of a CO_2 leak within marine waters will be highly localized close to the leak. This emphasises the challenge of designing a monitoring program capable of covering a large area, while simultaneously capable of detecting small and localized changes in the marine environment.
- The challenge increases when recognising that the natural variability of the marine environment, may cover any signal from a leak. As long as the signal stays below natural variability it will be extremely hard to detect, localize and quantify a leak.
-Other, natural or man-made, events might trigger changes in the environment that can be misinterpreted as indicators of a leak. Unless these are explained they might cause unfounded allegations of a leak.
-Each site will be different, and there might be different environments within the domain of individual projects. Hence, the approach might differ from project to project.
-The costs of marine operations are considerable and instrument capabilities will constrain the design of a monitoring program.
-Quantification of uncertainties will be a challenge.

Conclusions/recommendations.

A proper statistical description of the environmental baseline is intrinsic for estimating spatial and temporal distribution of a leak footprint. Such estimates allow for subsequent exposure assessments and provide the basis for designing a monitoring program. To account for natural trends and rare events, i.e. tails of the distributions, a long period of data is required. As a result it is recommended that the baseline statistics gathering begins during the characterization and assessment of a storage site, and that one of the objectives of the monitoring program is to improve the environmental statistics.