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CCS Future Report

1. Major results of the ECO2 project

ECO_2 conducted a comprehensive offshore field programme at the Norwegian storage sites Sleipner and Snøhvit and at several natural CO_2 seepage sites in order to identify potential pathways for CO_2 leakage through the overburden, monitor seep sites at the seabed, track and trace the spread of CO_2 in the water column, and study the response of benthic biota to CO_2. ECO_2 identified a rich variety of geological structures in the broader vicinity of the storage sites that probably served as conduits for gas release in the geological past and located a seabed fracture and several seeps and abandoned wells where natural gas and formation water are released into the marine environment. Even though leakage may occur if these structures are not avoided during site selection, observations at natural seeps, release experiments, and numerical modelling revealed that the footprint at the seabed where organisms would be impacted by CO_2 is small for realistic leakage scenarios.

Based on these findings, a new approach for environmental risk assessment (ERA) was developed for sub-seabed storage sites. It uses the EBSA (Ecologically or Biologically Significant Marine Areas) approach to describe marine resources in the studied area and to assess a site-specific environmental value for each highlighted resource. Subsequently, potential leak features that can connect the CO_2 stored in the target formation with the seabed are identified and the size of the affected seafloor is estimated for a range of leakage scenarios. Overlay analysis between the affected area and the identified valuable resources reveal the consequences of leakage. Bayesian methods are applied to determine a propensity-to-leak factor dealing with the geological complexity of the overburden. The environmental risk is finally assessed as the product of consequences and propensity of leakage. The novel ERA approach was tested and applied to assess the environmental risks of the storage operation conducted at Sleipner.

The monitoring strategy proposed by ECO_2 is organized around a suite of surveys covering the area above the storage formation. ECO_2 recommends that overburden, seabed, and water column should be monitored and surveyed applying the following techniques: i) 3-D seismic, ii) high-resolution bathymetry/backscatter mapping of the seabed, iii) hydro-acoustic imaging of shallow gas accumulations in the seabed and gas bubbles ascending into the water column, iv) video/photo imaging of biota at the seabed, v) chemical detection of dissolved CO_2 and related parameters in ambient bottom waters. Additional targeted studies have to be conducted if active formation water seeps, gas seeps, and pockmarks with deep roots reaching into the storage formation occur at the seabed. These sites have to be revisited on a regular basis to determine emission rates of gases and fluids and exclude that seepage is invigorated and pockmarks are re-activated by the storage operation. Baseline studies serve to determine the natural variability against which the response of the storage complex to the storage operation has to be evaluated. All measurements being part of the monitoring program, thus, need to be performed during the baseline study prior to the onset of the storage operation to assess the spatial and temporal variability of leakage-related structures, parameters, and processes.

Finally, guidelines for environmental practices in implementation and management of sub-seabed storage sites were formulated by the ECO_2 consortium. This high-level document includes i) an overview on the legal framework that needs to be considered in the planning and operation of storage sites, ii) an assessment of the public perception of sub-seabed CO_2 storage, iii) a novel framework for the assessment of environmental risks, iv) criteria and recommendations for site selection in the marine environment and v) recommendations for environmental monitoring and baseline studies at sub-seabed CO_2 storage sites.

2. Dissemination of project results

EU funding through "The Ocean of Tomorrow" facilitated bringing together leading European experts from three key disciplines: ocean acidification, natural seepage, and CCS, from research and industry (e.g. Statoil) to jointly investigate, in a multidisciplinary way, the impact of sub-seabed CO_2 storage on marine ecosystems. The project provided the first comprehensive assessment of environmental risks associated with sub-seabed CO_2 storage and a novel and comprehensive monitoring strategy for sub-seabed storage sites able to detect episodic events and prolonged low-flux leakage. All ECO_2 results were evaluated and combined in a best environmental practice guide for the implementation and sustainable management of sub-seabed CO_2 storage sites, as the final product of the project. The investigations of the project provide the EC, national policy makers as well as stakeholders on CCS and scientist with all relevant information on environmental risks, monitoring strategies, permanency, safety, and perception of sub-seabed CO_2 storage. Accordingly, ECO_2 assures the pooling of capacities, short-term scientific exchange, and the validation and dissemination of results throughout Europe and beyond.

Dissemination of project information and results took place on many levels, but chiefly in three areas: i) to the general public; ii) to the wider scientific community; iii) to policy-makers, regulators, and storage site operators.

Dissemination to the general public was mainly addressed by providing the ECO_2 website, the ECO_2 brochure, the click and learn tool on monitoring, and videos explaining the concepts of CCS, CO_2 storage, and ECO_2 in graphical animations and lay terms. All the studies performed on public perception have been made available to the wider public with a lay terms report, which presents the information in a way that is easily accessible to all, with short texts in plain English, structured to facilitate comprehension of key concepts and their practical implications and cartoons to stimulate interest. Another important tool was produced for facilitating comprehension of CCS related terms, a CCS Glossary, both downloadable and with easy searchable terms on the website.

The scientific publications generated by the project combined with the dissemination of project results via conference presentations, invited talks, international seminars and workshops formed the key route by which results were broadcast to the wider science community. Additionally, project publications and key results were made available via the project website and aimed at a wider audience with a broad scientific knowledge.

Stakeholders addressed by ECO_2 included current and new storage site operators, SMEs offering monitoring techniques and other relevant equipment and expertise, regulators and policy makers at the

EU and the national level, and NGOs. The policy stakeholder dialogue process was implemented as a vehicle to provide key stakeholders with the scientific knowledge necessary to facilitate implementation and management of environmentally sound offshore storage. This dissemination occurred via scientific briefing papers which were presented to CCS stakeholders at the EU parliament and other relevant levels during dedicated workshops or lunch briefings.

The Scientific Advisory Board (SAB) and Stakeholder Dialogue Board (SDB) of ECO_2 both had a strategic and an active role in the use and dissemination of Intellectual Property generated by the project. As external contributors to the project they informed project partners about the most effective means of disseminating their results, including providing information to the project about new committees, government or commercial initiatives. They contributed significantly to the success of the project and the dissemination of project results to the scientific community (SAB) and the various stakeholders involved in CCS (SDB).

3. Open questions and future research needs

New questions emerged as a result of the research conducted by ECO_2 and the surprising discoveries made by ECO_2:

i) ECO_2 discovered numerous vertical structures cutting through the overburden in the vicinity of all storage sites. Natural gas was released from storage formations via these seismic chimneys and pipes in the geological past. However, ECO_2 was not able to determine the present-day permeability of these structures and could therefore not predict at what rate CO_2 would leak if stored beneath these structures. Future research projects should thus aim to drill into seismic chimneys and pipes to characterize their internal structure and permeability.

ii) The Hugin Fracture discovered by ECO_2 is the first of its kind. It is associated with subsurface channel structures that may act as conduits for CO_2 leakage. Its discovery was enabled by new technologies employed by ECO_2. We do not presently know whether this structure is unique or a common feature of sedimentary basins harboring channel structures. Hence, the seabed should be mapped using cutting-etch technologies to find out whether differential compaction of subsurface channel structures leads to seabed fracture not only at the Hugin site but also elsewhere.

iii) Field work at natural CO_2 seeps, a CO_2 release experiment at the seabed, and modelling studies revealed that sessile benthic organisms living close to a CO_2 leak experience strong changes in ambient bottom water properties fluctuating from background to acidic conditions within hours or even minutes. Thus, these organisms have to cope with an extreme pH and CO_2 variability rather than a constant exposure to low pH/high CO_2 conditions. Their physiological plasticity may allow many benthic organisms to cope with this type of exposure. However, the limits of this plasticity are only poorly understood.

Thus, future experimental studies should expose biota to dynamic rather than constant pH/CO_2 conditions to better understand how organisms settling next to leak sites respond to CO_2 exposure.

iv) ECO$_2$ formation water experiments indicate that salt-rich and oxygen-depleted fluids would severely impair benthic marine fauna even though the level of hypoxia (50 µM O_2) and the increase in total salinity simulated in these experiments (48 psu) is milder than the conditions often observed in formation fluids. Marked changes were observed in most of the measured responses. Comparatively, for many of these responses, these results far exceeded the impact of the exposure to even the most severe CO_2 treatments observed in the project. Thus, future studies on monitoring and environmental risks should aim to detect formation water leakage at an early stage and to fully assess its effects on benthic biota.

v) Operational costs for the monitoring approach proposed by ECO$_2$ are substantial. These costs could be reduced using cutting-edge technologies such as long-range autonomous vehicles and a new generation of in-situ sensors. These and other new technologies should be further developed and optimized by future projects to reduce costs for monitoring and baseline studies at sub-seabed CO_2 storage sites.

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