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Developing a geochemical baseline for diagnosis of potential anthropogenic CO2 seepage in seafloor sediments offshore Norway

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Geological carbon capture and storage (CCS) in deep saline aquifers is an expanding strategy for climate change mitigation, requiring secure containment of CO2 for at least 10,000 years. Demonstrating the absence of leakage is often more practical than detecting active seepage, and noble gas signatures offer a promising geochemical tool for this purpose. Offshore Norway has hosted CO2 storage operations for decades, with increasing numbers of sites and cumulative injected volumes. While large-scale monitoring is typically conducted using geophysical methods, the ICO2P project (2019–2021) investigated noble gas systematics in captured CO2 streams to evaluate their applicability as natural tracers.

Gas samples from Norwegian CCS test sites at Melkøya, Mongstad, and Klemetsrud were analyzed for isotopic compositions. Trace gas variability at TCM was measured using a miniRUEDI gas-equilibrium membrane-inlet mass spectrometer (GE-MIMS) [1,2]. All captured CO2 streams showed depletion in total noble gas content; however, isotopic signatures and relative noble gas abundances varied systematically with CO2 source and capture process. Following injection and storage, any migration of CO2 in the geosphere is expected to strip noble gases from formation waters, thereby acquiring a site-specific geochemical fingerprint dominated by in situ reservoir conditions. Artificial tracers such as Xe and Kr may be added, providing also an early warning function. While considered quite costly, prices have dropped significantly in the last few years.

Complementary baseline surveys were conducted in the North Sea above the prospective storage sites Smeaheia and Aurora. Deep seawater (300 m) and shallow sediment porewater (10 - 75 cm) were sampled to characterize natural noble gas backgrounds and accumulation rates, particularly near regional faults intersecting reservoir–seal successions. The results demonstrate that naturally occurring noble gas signatures can serve as cost-efficient tracers for excluding leakage from offshore storage reservoirs and abandoned wells. Comprehensive baseline characterization of multiple fluid sources and migration pathways, conducted before and during drilling and injection, provides a robust framework for identifying and quantifying potential seepage signatures.

[1] Brennwald, Schmidt, Oser & Kipfer (2016) Environ.Sci.&Tech., 50, 24.

[2] Weber, Kipfer, Horstmann, Ringrose, Kampman, Tomonaga, Brennwald & Sundal (2021), IJGHGC,106, 103238.