Strategies for Environmental Monitoring of Marine Carbon Capture and Storage

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STEMM-CCS



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Strategies for Environmental Monitoring of Marine Carbon Capture and Storage

STEMM-CCS is an ambitious multi-disciplinary project that will deliver new approaches, methodologies and tools for the safe operation of offshore carbon dioxide capture and storage (CCS) sites. CCS is a powerful mitigation strategy for addressing the increasing levels of carbon dioxide (CO_2) in the atmosphere. The storage of CO_2 in underground reservoirs, for example in depleted oil and gas fields or aquifers, is a demonstrated technology on land and - to a more limited extent - in marine systems. STEMM-CCS will develop approaches to help ensure we select appropriate marine storage sites and can monitor them effectively, thus further increasing confidence in CCS as a viable option for reducing atmospheric CO_2.

Drawing together expertise from across academia and industry, STEMM-CCS will provide a set of tools, techniques and methods to enhance our understanding of CCS in the marine environment. We will identify new cost-effective ways to establish environmental and ecological baselines, advance understanding of how CO_2 can move through the subsurface, and develop new techniques for the efficient and accurate detection of any CO_2 escape. Many of our activities will lead to the development or enhancement of sensing technologies, which also have applications beyond the CCS arena and may be suitable for commercialisation. Throughout the project there will be a high level of engagement with policy makers and stakeholders to ensure the widest possible exchange of knowledge, including with countries outside Europe that are currently developing offshore CCS.

The key project objectives are:

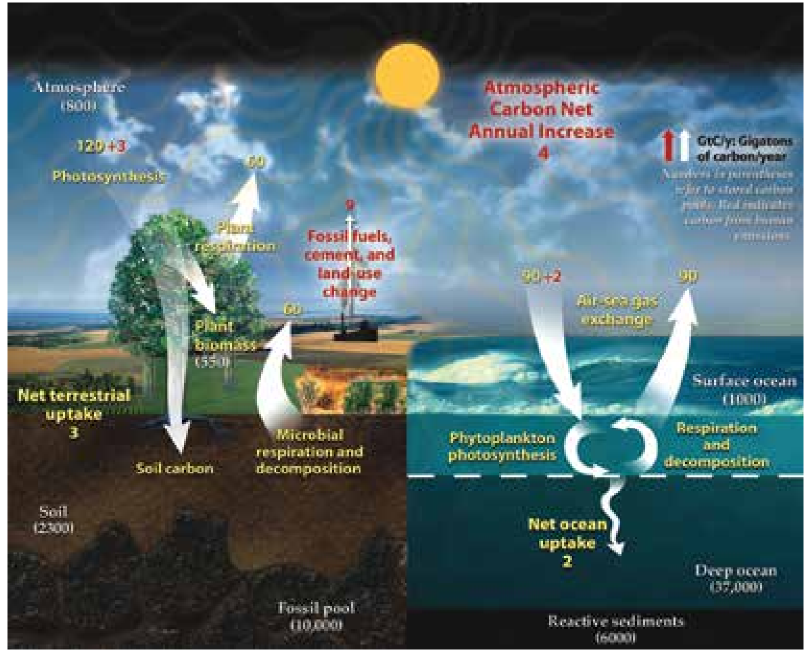
1. Develop methods for assessing the ability of CO_2 to permeate through the overlying seafloor sediments at offshore CCS sites, in terms of both the natural system and where CO_2 has been artificially introduced.
2. Build on best practice from previous CCS research to develop a robust methodology for establishing environmental and ecological baselines under 'real life' conditions.
3. Develop a suite of cost-effective tools to identify, detect and quantify CO_2 leakage from a sub-seafloor CCS reservoir.
4. Assess the suitability of artificial and natural chemical tracers for the detection, quantification and mapping of escaped CO_2 in the marine environment.
5. Model and assess the local, regional and wider impacts of different reservoir CO_2 leak scenarios and provide decision support tools for monitoring, mitigation and remediation action.
6. Deliver documented best practice for selection and operation of offshore CCS sites and to transfer knowledge to industrial and regulatory stakeholders through education and training programmes.
7. Liaise with the local communities, share knowledge and thus increase confidence in the physical security of CCS.

Sources and sinks of CO_2

Carbon dioxide is a natural component of our atmosphere: it is essential for sustaining life on our planet, and is a key component in the biogeochemical cycles that drive our ecosystems. CO_2 is naturally produced through the decomposition of organic matter, release from the ocean and respiration. These sources of CO_2 are roughly balanced by natural sinks such as photosynthesis and absorption by the oceans, keeping the fluxes of CO_2 broadly in equilibrium.

However, carbon dioxide is also produced from industry, mainly through deforestation and the burning of fossil fuels. Scientific data show that the concentration of CO_2 in the atmosphere has increased by more than 40% since the industrial revolution, and its present concentration is the highest in the last 800,000 years. The past 10 years alone have seen unprecedented rates of increase and our planet's natural CO_2 sinks are unable to keep pace.

Increased levels of atmospheric CO_2 have serious implications for the global climate. CO_2 is a potent greenhouse gas and its rising concentration in the atmosphere is a fundamental driver of global warming and ocean acidification; both have been identified as major challenges to the health of our planet.



This diagram of the carbon cycle shows the movement of carbon between land, atmosphere, and oceans. Yellow numbers are natural fluxes, and red are human contributions in gigatons of carbon per year. White numbers indicate stored carbon. Image courtesy NASA/adapted from U.S. DOE, Biological and Environmental Research Information System.

Image: Statoil

Carbon dioxide Capture and Storage (CCS) has been identified as an important strategy to mitigate anthropogenic CO_2 emissions. The aim of CCS is to take CO_2 from large emission sources, such as power stations, transport it to a storage site and permanently lock it away so that it cannot be released into the atmosphere. CCS storage sites are usually geological formations deep underground, either onshore or offshore.

CCS is seen as a key contribution to the target of reducing anthropogenic greenhouse gas emissions into the atmosphere by 80-95% by 2050 in order to keep climate change-derived temperature increases below 2°C. This target was agreed by parties to the United Nations Framework Convention on Climate Change (UNFCCC) in 2015, and outlined in the European Commission's 'Roadmap for moving to a competitive low carbon economy in 2050'.

To date, CCS has mainly been developed using land-based storage reservoirs (for example, Shell's Quest CCS project in Canada). Currently there are two operational marine CCS sites in Europe, located at Sleipner in the central North Sea (pictured) and at Snøhvit in the Barents Sea. There is potential for many more marine CCS facilities to be developed and the process of identifying suitable locations is ongoing, but monitoring them during operation in a reliable, cost-effective and accurate manner needs to be established. In addition, there is clear scope to develop more cost-effective, accurate and reliable marine monitoring technologies to support large-scale deployment of CCS. STEMM-CCS will provide solutions to these challenges and will considerably advance our knowledge and understanding of the risks, challenges and benefits of geological CCS in the marine environment.

Project approach

STEMM-CCS combines a unique set of field experiments alongside laboratory work and mathematical modelling. A number of research cruises will take place in the North Sea, where a combination of existing state-of-the-art technology and new sensors and techniques developed by the project will be deployed to examine baseline conditions, sub-seafloor structures, fluid pathways and a range of other characteristics relevant to the safe operation of CCS in the marine environment.

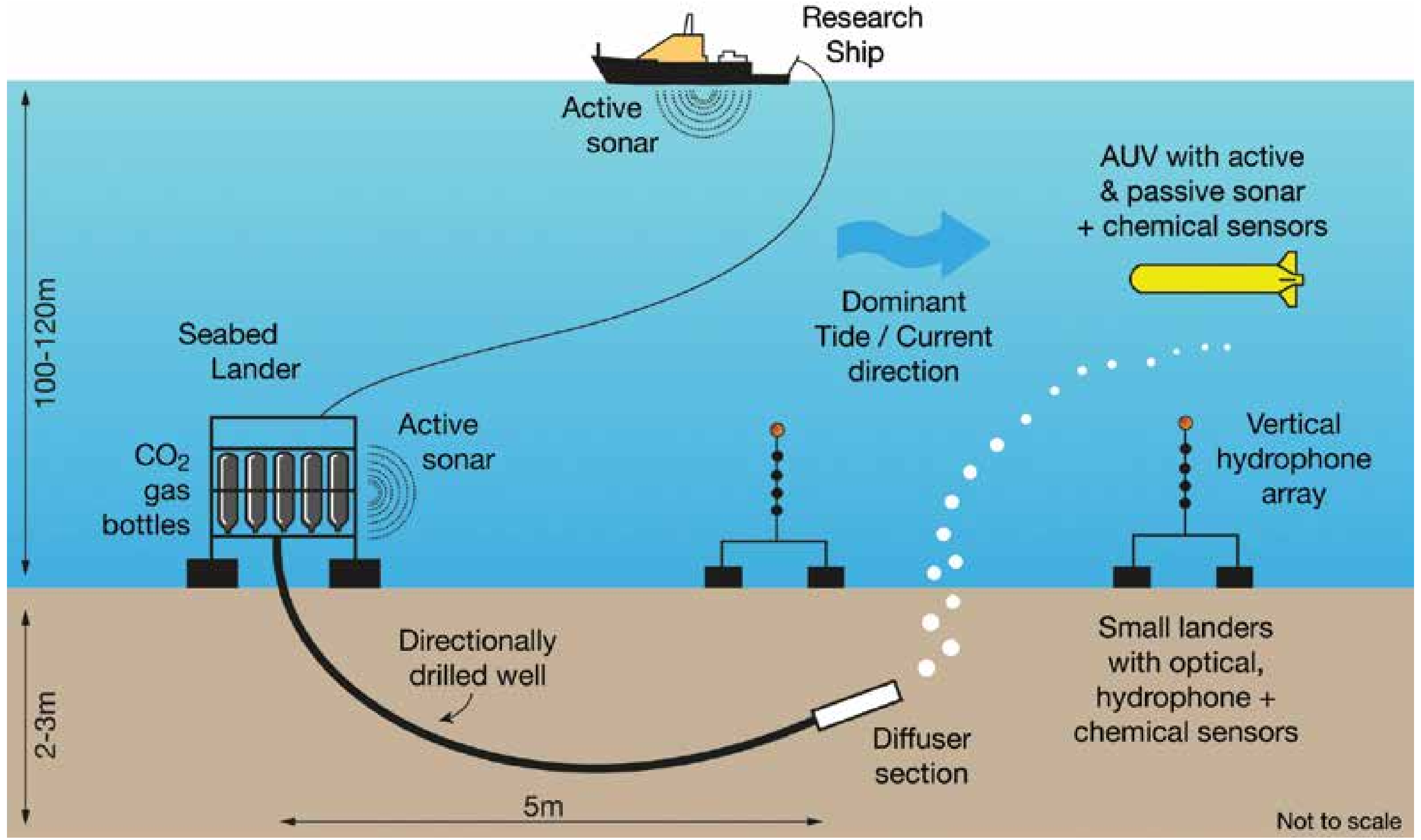
A key component of the project is an experiment in the North Sea at the Goldeneye site, which has been identified as a potential CCS storage complex. Here, CO_2 gas will be released via a drill hole beneath the seabed and its pathway to the seafloor and into the water column tracked and monitored. Prior to the experiment, baseline environmental conditions both at the seafloor and in the overlying water column will be established so that the released CO_2 can be differentiated from the CO_2 naturally present in the marine environment.

A variety of sensors and indicators will then be used to detect and quantify the released CO_2, track its dissipation through seafloor sediments and into the water column, and monitor its effects on the surrounding environment. These will include chemical sensor arrays mounted on benthic landers and water column moorings to "sniff" for evidence of release; active sonar devices and hydrophone arrays to "listen" for CO_2 bubbles, and Autonomous Underwater Vehicles (AUVs) equipped with passive sonar and chemical sensors patrolling the area. This experiment is unique as it will allow measurement and monitoring of CO_2 escape under real subsea conditions at a potential CCS site. It will provide a platform for the testing of new techniques, sensors and sensor combinations, and novel integrations of models, instruments and platforms for the detection and quantification of CO_2 escape.

The extensive field and laboratory-based experiments, together with the development and application of innovative techniques, engineering solutions and new technologies, will generate a huge amount of new knowledge to underpin recommendations for future best practice and operational support. STEMM-CCS will share its results with a broad range of stakeholders, including regulatory bodies, policymakers, industry groups, academia and the wider CCS community. Public perception of CCS is important for its acceptance as an effective measure against climate change, and STEMM-CCS will ensure that clear and accessible information about sub-seabed CO_2 storage is available to all who need it.

Right: Schematic diagram showing the planned controlled release experiment in the North Sea. CO_2 gas will be released from a sub-seabed source, and its pathway through the seafloor sediments and into the water column tracked, monitored and quantified by a range of novel techniques and instruments, including passive and active sonar and chemical sensors mounted on the research vessel, underwater moorings and Autonomous Underwater Vehicles.

The STEMM-CCS controlled release experiment



Artist: K. Davis

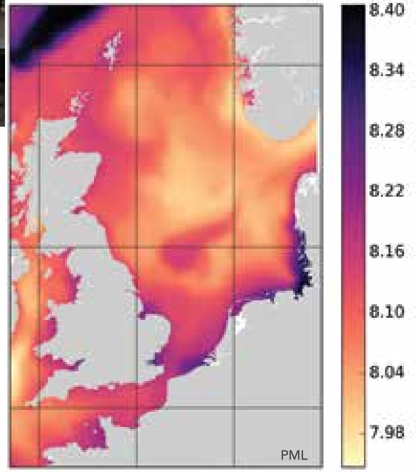
Establishing baselines

Efficient and accurate detection of CO_2 leakage from CCS sites is critically dependent on having detailed and reliable knowledge of the natural environmental and ecological baselines around the storage site, so that deviations from "normal" conditions can be quickly detected and traced.

Establishing a baseline at a storage site is a hugely complex and potentially costly exercise, requiring detailed observation and measurement of a wide range of parameters that encompass the physical, biological and chemical characteristics of seawater and the seafloor environment. Understanding the degree of variability in these characteristics over different spatial and temporal scales (episodic, seasonal, annual, decadal) is crucial for the effective and safe monitoring of CCS operations.

STEMM-CCS will establish a sound baseline for our North Sea experimental site. Observational, analytical and modelling techniques will map geomorphology and biological community structure, quantify the spatio-temporal variability of key chemical parameters in both water column and sediments, develop indices for biological community composition and health, and provide estimates of the existing stressors (e.g. trawling, pollution). Models will deliver comprehensive fields of physical and chemical properties, enabling predictions and projections of future baseline conditions against which regulators and operators will be able to plan and future-proof environmental modelling.

Streamlining the baseline process is a key objective of STEMM-CCS, resulting in economically efficient and high quality monitoring strategies for both CO_2 escape detection and impact identification.



Autonomous vehicles such as Autosub (above) will be used to collect environmental data to feed into baseline models. Direct observations and predictive models will be used to monitor the marine environment around CCS storage sites: together they will allow detection of anomalous measurements against expected background values, whilst allowing for natural variations. Right: model data showing annual mean pH at the seafloor.

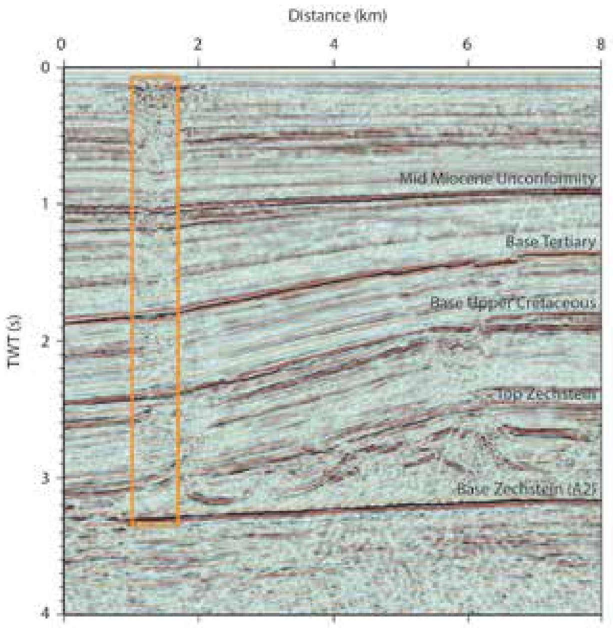
Understanding CO_2 pathways

The location and likely intensity of CO_2 leakage from a CCS site depend crucially on the distribution, orientation and permeability of fluid pathways in the subsurface. Sub-seafloor geological structures known as chimneys can be up to 500m wide and commonly occur in sedimentary basins such as the North Sea. Thought to have formed as a result of fluid migration, they present potential leakage pathways from a storage complex to the seabed and therefore require careful investigation.

STEMM-CCS will use new 3D seismic and sediment imaging techniques alongside direct sampling to investigate fluid pathways in seafloor sediments. A comprehensive geophysical investigation of a known chimney structure will yield important data on its permeability characteristics. Combined with direct sampling of fossil chimney structures on land, this will enable numerical models to be developed that give quantitative predictions of the efficiency of fluid flow through such structures. Permeability created by fracture networks in subsurface sediments will be assessed via borehole sampling, geophysical seafloor imaging techniques and cutting-edge 4D seismic technology.

When combined, these datasets will form the basis for a numerical modelling study of overall fluid migration patterns and expected volumes. These results will inform the design of a state-of-the-art cost-effective geophysical survey of the near-surface geology at the Goldeneye site in order to assess the potential for CO_2 escape and to identify priority locations for monitoring.

Right, upper: Seismic surveying using the P-Cable system (image courtesy Fugro). Right, lower: Seismic reflection section illustrating a chimney structure in the German sector of the North Sea (Schlesinger, 2006). The chimney (boxed in orange) cuts through the top c. 3 km of the sedimentary overburden (c. 3 secs two-way travel, TWT).



Detecting, tracing and quantifying leakage

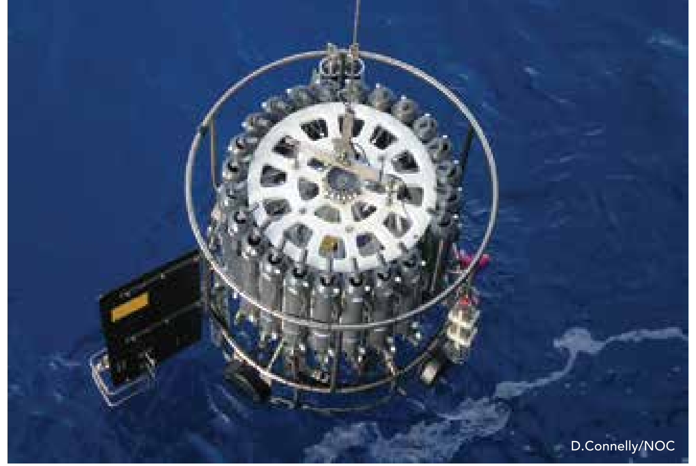
The ability to efficiently and accurately detect, trace and quantify CO_2 leakage from storage reservoirs is critical for ensuring the safe operation of CCS in the marine environment. STEMM-CCS will determine the most viable and effective methods of detecting any escape, focusing on both the physical expression of CO_2 as gas in seafloor sediments and the water column, and the chemical dynamics of CO_2 in the dissolved phase.

New sensors and detection techniques developed during the project will be tested during the controlled release experiment. The most visually-obvious evidence of CO_2 escape - bubbles - will be monitored using active and passive sonar alongside visual surveys to detect, quantify and trace bubble streams in the water column.

Other indicators of potential CO_2 escape include displacement of natural fluids and gases from the surrounding sediments, which can be detected against expected background levels established during baseline assessment. Such seepages are likely to precede any CO_2 escape, and can therefore act as an early warning of reservoir integrity breach.

Artificial tracers have been successfully used in land-based CCS projects but have yet to be fully tested for use in marine storage systems. A range of chemically and isotopically distinct substances will be added to the CO_2 in the controlled release experiment. This will allow us to assess their suitability as sensitive tracers of gas movement through the marine environment, to quantify the volume and rate of release, and to investigate how the CO_2 interacts with the sediments.

Data collected during these studies will feed into the models developed during the baseline exercise to produce a comprehensive model system capable of simulating leakage scenarios and environmental effects at a variety of spatial scales.



D.Connelly/NOC

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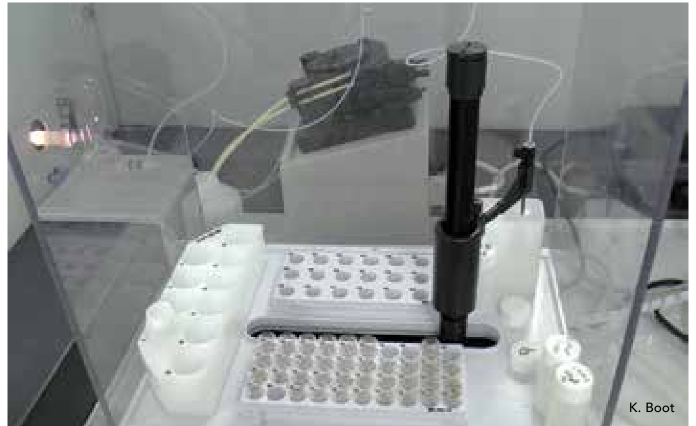

K. Boot

Technology and innovation

Innovation and technology development is at the core of STEMM-CCS. From major engineering challenges to improvements in the detection of CO_2 escape, we will go beyond the current state-of-the-art in crucial areas that will provide confidence in the large-scale roll-out of operationally safe and environmentally sound CO_2 storage in offshore geological reservoirs. This innovation will include the design and application of new techniques and strategies, as well as the development and/or improvement of instruments and platforms for the detection and quantification of CO_2 escape.

Specifically, STEMM-CCS will make the following advances:

- Develop methods to constrain the permeability of sediments overlying CCS reservoirs and enable evidence-based potential CO_2 leakage risk assessment where currently there is a wide range of opinion.
- Develop observational techniques and models to enable cost- and resource-efficient acquisition of baseline conditions in the vicinity of marine CCS sites, encompassing the natural short- and long-term changes in biological and biogeochemical variables. This will provide the data needed to discriminate CCS CO_2 leakage from other natural or anthropogenic sources.
- Develop cost-effective tools for detection and quantification of CO_2 escape, including new techniques and sensors, new sensor combinations and new integrations of models, instruments and platforms.
- For the first time in a CCS-related project, test artificial and natural tracers by co-injection with the CO_2 in the sub-seafloor release experiment to monitor the dynamics of the injected CO_2 through the sediment column into the overlying water column.
- Develop methods to assess anthropogenic CO_2 release against a background of varying natural CO_2 fluxes across sediment-water interfaces. This has been applied in terrestrial CCS but not offshore.
- Develop models for the local, regional and wider expressions of different reservoir leak scenarios and provide decision support tools for mitigation and remediation action.

D. Oswianka/NOC

The STEMM-CCS partnership

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