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Environmental considerations for subseabed geological storage of CO_2: A review

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ABSTRACT

Many countries are now using or investigating offshore geological storage of CO_2 as a means to reduce atmospheric CO_2 emissions. Although associated research often focuses on deep-basin geology (e.g. seismic, geomagnetics), environmental data on the seabed and shallow subseabed is also crucial to (1) detect and characterise potential indicators of fluid seeps and their potential connectivity to targeted storage reserves, (2) obtain baseline environmental data for use in future monitoring, and (3) acquire information to facilitate an improved understanding of ecosystem processes for use in impact prediction. This study reviews the environmental considerations, including potential ecological impacts, associated with subseabed geological storage of CO_2. Due to natural variations in CO_2 levels in seafloor sediments, baseline CO_2 measurements and knowledge of physical–chemical processes affecting the regional distribution of CO_2 and pH are critical for the design of appropriate monitoring strategies to assess potential impacts of CO_2 seepage from subseabed storage reservoirs. Surficial geological and geophysical information, such as that acquired from multibeam sonar and sub-bottom profiling, can be used to investigate the connectivity between the deep reservoirs and the surface, which is essential in establishing the reservoir containment properties. CO_2 leakage can have a pronounced effect on sediments and rocks which in turn can have carryover effects to biogeochemical cycles. The effects of elevated CO_2 on marine organisms are variable and species-specific but can also have cascading effects on communities and ecosystems, with marine benthic communities at some natural analogue sites (e.g. volcanic vents) showing decreased diversity, biomass, and trophic complexity. Despite their potential applications, environmental surveys and data are still not a standard and integral part of subseabed CO_2 storage projects. However, the habitat mapping and seabed characterisation methodology that underpins such surveys is well developed and has a strong record of providing information to industry and decision makers. This review provides recommendations for an integrated and interdisciplinary approach to offshore geological storage of CO_2, which will benefit national programs and industry and will be valuable to researchers in a broad range of disciplines.

1. Introduction

Reducing anthropogenic carbon dioxide (CO_2) emissions is an essential requirement for alleviating the potential and realised impacts of climate change and ocean acidification (The Royal Society, 2005; IPCC, 2007; Hoegh-Guldberg and Bruno, 2010). CO_2 is considered the most important greenhouse gas (GHG) due to its relative abundance in the atmosphere compared to other GHGs, and the dependence of the world economies on fossil fuels as a primary energy source (IPCC, 2005). It is estimated that global energy demand and CO_2 emissions will more than double by 2050 (IEA/OECD, 2008; IEA, 2010), placing increased pressure on governments to seek new options for mitigation of CO_2 impacts. Indeed, many countries have committed to reduce carbon emissions within stringent timeframes (e.g. pledged emission reductions by 2020: EU member states, 20–30% relative to 2005 levels; USA, 17% relative to 2005; Russia, 15–25% relative to 1990; Australia, 5–25% relative to 2000) (Stern and Taylor, 2010; Flannery et al., 2012) in an attempt to limit global temperature rise and ocean acidification. Stabilisation scenarios of the International Energy Agency (~450 ppm CO_2 equivalents or 2 degree scenario) however, will require a reduction of global CO_2 emissions of at least 50% by 2050, relative to 2000 levels (IEA, 2010; IPCC, 2011).

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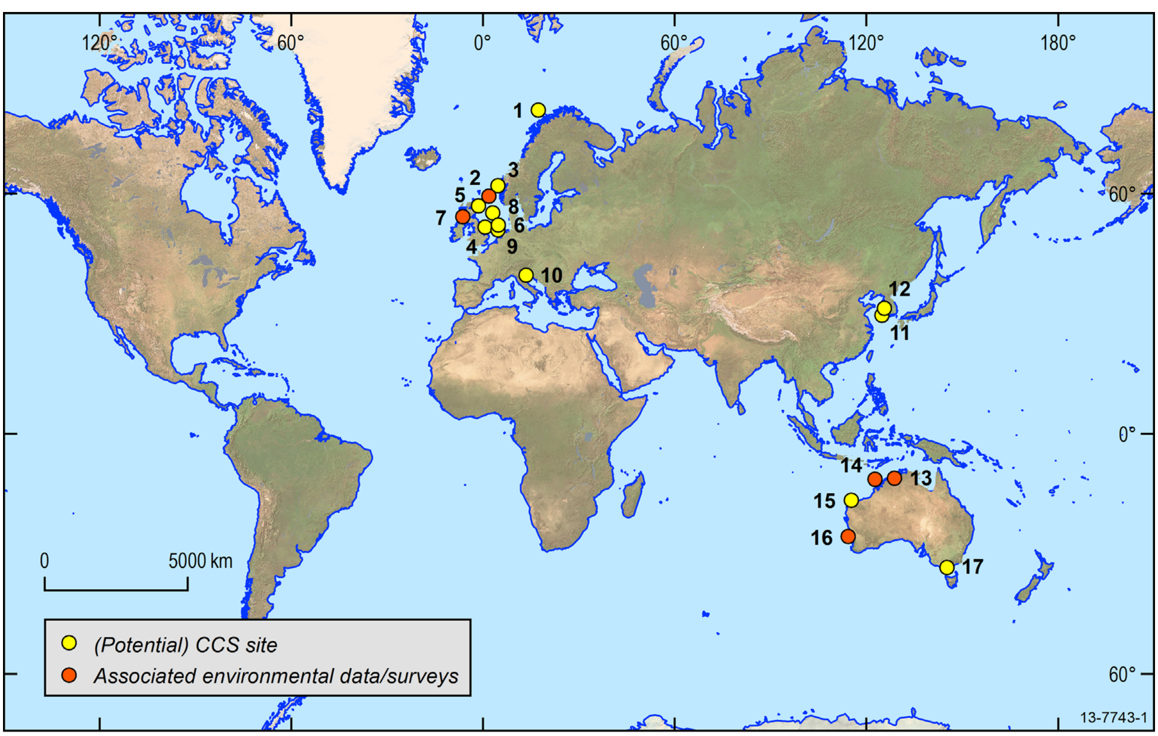
Attaining these challenging goals will therefore require the rapid implementation of CO_2 mitigation measures and technologies, including improved energy efficiency and the adoption of marine renewable energy sources and carbon capture and storage systems (CCS).

Subseabed geological storage of CO_2 is among a suite of CCS methodologies (see Pires et al., 2011) that has the potential to partially reduce anthropogenic carbon emissions in the medium to long-term (Holloway, 2005; IPCC, 2005, 2011; Holloway et al., 2007). The process involves capturing CO_2 from a point emission source (e.g. a power plant, see Gibbins et al., 2006), compressing it for transportation via pipeline or ship, and injecting it into permeable formations (reservoirs) deep beneath the seafloor (Holloway, 2005; Metz et al., 2005). The transportation, injection and storage of large volumes of highly pressurised CO_2, however, raises concerns about the potential for CO_2 leakage and its associated environmental consequences on marine systems (Hawkins, 2004). Mechanisms for leakage can include fast flow events such as pipeline failure, faulty injection well castings, transmissive faults or fractures in cap rock, and seepage through porous geological structures (Blackford et al., 2008, 2009; Israelsson et al., 2010; Koornneef et al., 2010; Armitage et al., 2013). Although highly dependent upon the magnitude and duration of exposure, experimental investigations and modelling studies suggest that leakage of CO_2 into sediments and deep seawater will result in localised reductions in pH and lead to a cascade of biogeochemical alterations with detrimental impacts on benthic organisms, communities and ecosystems (Bibby et al., 2008; Blackford et al., 2008, 2009; Ardelan et al., 2009). Hence, there is a fundamental need to identify, quantify and predict the potential environmental impacts of activities associated with subseabed geological storage of CO_2, prior to its implementation (Wildenborg et al., 2009; Widdicombe et al., 2013).

As an activity that is designed to support targeted reductions in atmospheric CO_2 emissions, the offshore geological storage of CO_2 shares the same broad objectives as the marine renewable energy industry. Furthermore, both the offshore CCS and renewable energy industries have similar requirements in terms of environmental baselines for assessment of potential impacts associated with the construction, operation or decommissioning of marine facilities (e.g. pipelines, moorings in Gill, 2005). To that end, seabed mapping and characterisation surveys provide an ideal way in which to build such baselines, as well as provide information about potential hazards that may hinder infrastructure development.

Although environmental information is deemed crucial for the implementation and review of marine renewable energy projects (e.g. wind farms in Lindeboom et al., 2011; ocean energy in Boehlert and Gill, 2010), the use of such information is only beginning to be included in offshore CCS programs. To date, the methodologies described in the literature typically focus on the characterisation of potential CCS sites at the level of reservoir and seal characterisation (Gibson-Poole et al., 2008; O'Brien et al., 2011; Arts et al., 2012; Donda et al., 2013). These studies, however, do not commonly use shallow subsurface and seabed information to help characterise the site, or establish baseline information for future monitoring purposes. This environmental information, coupled with systematic assessments of targeted CO_2 storage capacity at the national and large basin scale (Dooley, 2011),



1. *Snøhvit CO_2 Injection*
2. *Sleipner CO_2 Injection*
3. *CO_2 Capture Mongstad (CCM)*
4. *C GEN North Killingholme Power*
5. *Peterhead Gas CCS*
6. *White Rose CCS*
7. *QICS*
8. *Rotterdam Opslag en Afvang Demonstratieproject (ROAD)*
9. *Green Hydrogen*
10. *Porto Tolle*
11. *Korea CCS1*
12. *Korea CCS2*
13. *Petrel Sub-basin NLECI*
14. *Browse Basin NCIP*
15. *Gorgon LNG*
16. *Vlaming Sub-basin NCIP*
17. *CarbonNet Project*

Fig. 1. Locations of major offshore CCS sites as identified by the Global CCS Institute (www.globalccsinstitute.com), as well as several other known programs providing pre-competitive data (Browse, Petrel, Vlaming) and industry ventures (Gorgon LNG) (current as of April 2013). Sites at which environmental data or surveys are known to be included in site selection or monitoring are marked.