$CO_2$ storage in depleted or depleting oil and gas fields: What can we learn from existing projects?

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Abstract

Globally, there are now a number of examples of where $CO_2$ storage has exploited depleted or depleting oil and gas fields. Case-studies from these experiences highlight key learnings and allow a comparative assessment of requirements to be made between types of $CO_2$ storage projects from different geographic and regulatory contexts. This includes comparisons between storage operations in depleted fields with or without enhanced hydrocarbon recovery and storage in saline aquifers, and the approaches required in modelling, monitoring, reporting, economics, and operational strategies. Fundamental differences in the reservoir pressure and risk profiles between the types of storage are also explored. An aspiration of this study is, through the review of several storage and $CO_2$-EOR projects, to highlight factors that could aid or are perceived to be hindering development of $CO_2$ storage in depleted or depleting fields. Results are documented in a publically available report from IEAGHG (anticipated Q4 2016).

A selection of sites is reviewed, both pilot and commercial scale, including projects planned, operational and complete. These include the Goldeneye and Hewett gas fields, both in the UK North Sea and proposals in the recent UK government CCS demonstration competition; the K12-B and P18-4 gas fields, both in the Netherlands, the former is an enhanced gas recovery pilot, the latter is a planned commercial-scale project, known as "ROAD"; the Lacq-Rousse gas field pilot in France; the Cranfield and SACROC enhanced oil recovery (EOR) projects in Texas, USA; the Weyburn-Midale enhanced oil recovery project in Canada; and Otway, a gas field pilot in Australia. The Goldeneye, Cranfield, SACROC and Otway sites were selected as the main case-studies to demonstrate some of the issues of specific relevance to $CO_2$ storage in depleted or depleting hydrocarbon fields. These include:

**Risk assessment criteria.** The results from the Goldeneye bow-tie method and the Cranfield Certification Framework approach are examined. They were designed for different purposes: one to meet EU Storage Directive regulations, the other for more research-oriented goals.

**Monitoring criteria.** Parameters monitored during and post injection at the sites are identified. In particular, monitoring approaches to quantify the amount of $CO_2$ storage and to detect the extent of migration are explored. Recent developments and implications for monitoring requirements, including the effects of fluid replacement, are also discussed. Goldeneye is offshore and so has different monitoring logistics, notwithstanding the aforementioned different regulatory motivators, compared to the other sites. Its monitoring is very much tied to the risk assessment. Cranfield, SACROC and Otway deploy research-based testing and monitoring under different regulatory

regimes. Regulatory aspects to monitoring requirements were developed in concert with the Otway site operation. General differences in monitoring strategy between the types of site are also recognized. For example, difficulties in distinguishing $CO_2$ from residual hydrocarbon gas and the large number of well penetrations at depleted oil and gas fields have resulted in research into above-zone monitoring deployed at Cranfield and SACROC respectively. In the USA, these $CO_2$-EOR sites fall under oil & gas legislation (i.e. not GHG emissions focused), but none-the-less have their own incentives for monitoring $CO_2$ behaviour and avoiding emissions.

**Pressures changes & thresholds** in the case-studies are discussed in terms of limitations imposed and how these were mitigated. $CO_2$-EOR fields generally have a reduced pressure due to extraction of fluids, but have complex pressure responses from injection and production. Goldeneye, connected to the surrounding saline aquifer with neighboring hydrocarbon fields, has a different, but also evolving type of pressure profile through time. Pressure recovery from the natural water drive during and after production provides valuable information on boundary conditions that are important for assessing storage capacity and injection strategy.

**Storage capacity estimate validations** and the degree to which the case-studies are able to improve these estimates are investigated. Capacity predictions using dynamic numerical simulations are complex when residual hydrocarbon phases in addition to $CO_2$ and brine have to be taken into account. At Cranfield and SACROC, studies on the miscibility of $CO_2$ in the remaining oil are used to examine the effect this has on the accuracy of capacity estimates. Similarly, gas-mixing was investigated at Goldeneye. Direct monitoring of reservoir fluids during the filling of the Otway site allowed insight into the validity of the dynamic capacity estimations and of generic capacity estimates involving storage efficiency factors.

**Long-term wellbore integrity** assessments and proposed remediation measures are presented. Records of well incidents in Texas show no evidence of an increased rate of well failures related to $CO_2$-EOR operations. A sidetrack cement core taken from a 50 year old well with 30 years of $CO_2$ exposure at SACROC shows uncompromised structural integrity and suggests that degradation of cement is limited by diffusion of $CO_2$ and is insignificant on decadal time-scales. This evidence was cited in the Goldeneye well integrity assessment, which included a full-scale investigation into all the affected wells and mechanical modeling of the integrity of the cement and its bonding to the casing and formation.

**The cost of modifications and storage development** is discussed based on published figures from Goldeneye and Otway, and in terms of anecdotal comments on the economic viability of $CO_2$ storage at the $CO_2$-EOR sites.