Applied risk and consequence analysis for CO₂ storage projects – the Captain X storage site, offshore UK (ACORN)

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Introduction

Acorn is a proposed, scalable full-chain industrial CCS project, with collaboration between seven organizations across Europe funded by BEIS (UK), RCN (NO) and RVO (NL), and co-funded by the European Commission under the ERA-NET ACT instrument (http://www.act-ccs.eu) of the Horizon 2020 program. The aim of the project is to produce a development plan for a CCS hub that will capture existing industrial CO₂ emissions from the St Fergus Gas Terminal in north-east Scotland (UK), transport them via existing pipeline infrastructure, and store the CO₂ at the offshore Captain X storage site in the North Sea. A risk analysis on CO₂ leakage in the site was conducted using a methodology which allows a fast but precise identification and assessment of relevant leakage scenarios. The primary store of the Captain X site is the Lower Cretaceous Captain Sandstone Member, overlain by the Rodby and the Carrack shales as primary seals. The storage complex includes the Upper Cretaceous Chalk and a secondary store, the Palaeocene sandstones, which are overlain by the Lista shale (Figure 1).
Methodology

‘Threats’ (here defined as ‘leakage scenarios’) and ‘consequences’ are connected by a ‘top event’, the loss of containment, or leakage, which is defined as undesired CO₂ migration out of the primary store. The workflow consists of four steps:

1) **Leakage scenario definition stage**: Identification of potential leakage scenarios, i.e. migration pathways out of the primary store of Captain X. Two types of leakage scenarios were considered: ‘primary scenarios’ describing leakage out of the primary store; and ‘secondary scenarios’ describing leakage following ‘primary scenarios’ (Figure 2).

2) **Identification and assessment stage**: Risk and severity assessment by discussion of the relevant features, events and processes (FEPs) that enhance or reduce the risk of the leakage scenario to occur. The results were plotted on a risk matrix of likelihood of occurrence versus leakage severity (Figure 3).

3) **Threat barrier identification stage**: Suggestion and discussion of technical mitigation methods to reduce the risk in the different leakage scenarios.

4) **Consequence analysis**: Evaluation of the consequences, i.e. the impact of the occurring leakage scenario on: storage integrity, social acceptance, environment and hydrocarbon industry (mainly contemporaneous or future hydrocarbon production) and costs for remediation, penalties etc. The results are plotted on a spider diagram with a low, medium or high scale (Figure 4).
Figure 2: Leakage scenarios considered for the Captain X. In primary scenarios (blue arrows), CO$_2$ leaks 1) through primary seal; along 2) operating or 3) abandoned wells to the seafloor; along 4) operating or 5) abandoned wells into the secondary store; 6) laterally outside the storage complex; 7) into a deeper reservoir. In secondary scenarios (green arrows), CO$_2$ leaks 8) laterally outside the secondary store; 9) into the overburden; 10) to the seafloor along pathways outside the storage complex and 11) to the surface.

Results & Discussion
A multidiscipline project team participated in a workshop to discuss and quantify the risks and consequences of the Captain X storage site.

Figure 3: Risk matrix with all leakage scenarios considered for Captain X. Likelihood scale from 1 (very unlikely/to occur once in 10,000 years) to 5 (very likely/to occur once a year) and severity scale 1 (negligible) to 5 (>10% of the injected CO$_2$ leaked).

Figure 3 shows the risk of all leakage scenarios. All scenarios with a likelihood of three or higher involve migration along abandoned wells. Leakage scenario 4 (LS4; leakage along abandoned wells into secondary store) is considered the most likely leakage scenario. One well may pose a greater leakage risk than others because of its location close to the potential CO$_2$ migration pathway and because of its abandonment state, despite it having been abandoned to modern standards in 2007. Additionally, the lithology between the primary seal and secondary store is chalk, which presents some containment concerns should abandoned wells enable the CO$_2$ to bypass the primary seal. The main outcome of this risk analysis is to either consider remediating the higher risk well ahead of development, or to design injection strategies that minimize the interaction of injected CO$_2$ with that well. Geological leakage, migration across geological formations or structures (LS1), is less likely than leakage involving wells. In LS6 (lateral loss of containment), a moderate loss of CO$_2$...
could be expected. As in any largely unstructured open aquifer such as Captain X, up-dip lateral containment is a key concern and linked with the quantum of the injected inventory. The precise migration pathway is linked to structural definition of the top reservoir which, whilst monitorable, is of some uncertainty.

Spider diagrams are effective tools to compare the impact consequences of leakage scenarios. Figure 4 shows the low impact of LS4, compared to LS10 (leakage to seafloor outside the storage complex). Although LS4 is more likely and more severe than LS10, its consequences for storage security, social acceptance and the environment are less dramatic. The combination of leakage risk and consequence analysis for different scenarios provides the development team with a valuable tool to identify scenarios requiring risk reduction actions to effectively reduce potential impact. The methodology streamlines the risk assessment process while still producing output quality and accuracy.

References