OFFSHORE NORGE

Risk acceptance criteria for evaluation of leakage risk linked to plugged and abandoned (P&A) legacy wells within sites for geological storage of CO_2

The purpose of this memorandum is to propose criteria for determining when leakage risk (combination of likelihood of leakage and severity of environmental impacts from leakage) associated with a P&A legacy well can be regarded as acceptable without taking measures to strengthen the well's integrity.

1.Background

P&A legacy wells that penetrate a formation that is (planned to be) used for geological storage of CO_2 represent a potential leakage pathway. These wells must therefore be reviewed to determine the risk of leakage[1], and evaluate the need for preventive or corrective measures that can be used to stop leakage or otherwise reduce the leakage risk.

Measures to improve the integrity of permanently plugged wells that have potential for leakage can be challenging and involve high costs, especially offshore[2]. In a CO_2 storage context, small leaks will have very small environmental consequences, and the HSE risk and cost of well intervention[3] will normally be disproportionate to the corresponding avoidance of negative effects from unlikely, but possible leakage.

If storage projects need to plan for well intervention for any situation with risk of leakage along a legacy well, however small it might be, then this will significantly impact the economics of some projects. Consequently, we will see some storage resources not being utilised, and, in time, a corresponding lack of reduction of CO_2 emissions.

2.Key Initial considerations

Ambitious targets for CCS in Europe

The European Commission's Industrial Carbon Management Strategy (ICMS) indicates the need to store in geological formations some 50 million tonnes CO_2 per annum (Mtpa) in EU in 2030 and some 200 Mtpa in 2040. EU is not on track to achieve the 2030 target.

Lack of business case

The market conditions today generally do not provide a profitable business case for CCS development without additional support mechanisms, including public funding. This raises

[1] In this memorandum, leakage means release of CO_2 or formation fluids from the storage site. Formation fluids could be brine containing metals, traces of hydrocarbons, and well chemicals.
[2] The cost of well intervention for an existing P&A legacy well can be comparable to the cost of drilling and constructing a new well, and may exceed 500 million NOK.
[3] Well intervention in P&A legacy wells generally refers to rig-based intervention or intervention through an intercept well. See e.g. Method 2 and Method 3 on p. 39-40 in https://www.iogp.org/bookstore/product/well-abandonment-and-integrity-evaluation-for-co2-storage/.

the question: How can Europe maximise CCS development, with *environmentally safe geological storage*[4], at a low or acceptable financial burden to society?

Legacy wells are prevalent in most sedimentary basins

Suitable sites for geological storage of CO_2 are generally found in sedimentary basins that have been subject to hydrocarbon exploration and development, with many existing boreholes (wells). For sites within saline aquifers, such wells can either be dry (i.e. water-bearing) petroleum exploration wells where no economic reserves of hydrocarbons were found, or they may be wells targeting hydrocarbon fields underlying the aquifer.

Legacy wells are not necessarily P&A'd with consideration for CO_2 storage

The P&A design of wells is generally based on the applicable regulations and industry standards at the time of decommissioning and designed to isolate the hydrocarbon bearing formation(s) from fluid movement to overlying zones. The P&A design may therefore not properly isolate the target storage formation.

Overarching regulatory requirement - EU CCS Directive Art 4(4)[5]

'A geological formation shall only be selected as a storage site, if under the proposed conditions of use there is no significant risk of leakage, and if no significant environmental or health risks exist', where '*significant risk*' means a combination of a probability of occurrence of damage and a magnitude of damage that cannot be disregarded without calling into question the purpose of the Directive for the storage site concerned.

A restrictive interpretation of *'environmentally safe'* will increase overall costs to society

Interpretation of *'environmentally safe'* requires consideration of both 'local impacts to human health or the environment' and 'global effects from avoided release of CO_2 into the atmosphere'[6]. A restrictive interpretation of *'environmentally safe'* with attention only to local impacts may significantly increase the cost of reaching sufficient scale of CCS, including the total financial burden to the broader society through public support mechanisms.

3.Determining significance of environmental risk

The type and magnitude of potential *environmental impacts* depend on the presence of environmental resources within the area of possible influence, the degree of possible impact on these resources, and the vulnerability of the resources being impacted. Severity of environmental impacts is often represented in an *environmental consequence matrix*, with degree of impact along one axis, and vulnerability of resources along the other axis.

[4] EU CCS Directive, Art. 1(2): The purpose of environmentally safe geological storage of CO_2 is permanent containment of CO_2 in such a way as to prevent and, where this is not possible, eliminate as far as possible negative effects and any risk to the environment and human health.

[5] In the Norwegian CO_2 storage regulations, this requirement is reflected in § 1-10, 2. paragraph.

[6] EC, Guidance document 1, July 2024, CO_2 storage life cycle and risk management framework, Section 4.1.

Evaluation of environmental impact

If no vulnerable environmental resources are present within the area of possible influence, then, by default, any local environmental impact will be negligible. If, however, vulnerable environmental resources are present within the area of possible influence, then the storage project will need to assess the type and magnitude of environmental impact that can occur if leakage occurs, assuming that the leakage magnitude is according to predictions.

Typically, for expected leak rates for any relevant scenario with CO_2 leakage to seabed along an offshore P&A well,

- a pH-change sufficient to cause environmental impact will only occur in a small local disc with radius up to a few 10s of meters around the well[7];
- all CO_2 will typically be dissolved in the water column within 1-2 m above seabed[8].

This creates negligible or low environmental impact, depending on the presence of vulnerable environmental resources[9] within the disc area, and no impact to human health. This conclusion also often holds true for larger CO_2 releases. Even for blow-out scenarios or large pipeline releases, all CO_2 will be dissolved in the water column if the water depth is greater than 50-100 m[10]. A similar conclusion of negligible or low impact is found when considering the potential for release of formation fluids (e.g. brine)[11].

Evaluation of environmental risk

The likelihood of leakage along offshore legacy wells will need to be assessed based on the specific characteristics of each individual well, and the presence of driving forces[12], given the proposed storage site development plans. The operator can then deploy the project specific risk evaluation criteria[13] to determine if the combination of low likelihood and low severity of environmental impacts is not *significant*, i.e. does ***not*** call into question the purpose of the CCS Directive.

[7] Daniels S., Hardiman L., Hartgill D., Hunn V., Jones R., Robertson N., Deep Geological Storage of CO_2 on the UK Continental Shelf: Containment Certainty. UK Dep. for Energy Security and Net Zero. UK Dep. for Business, Energy & Industrial Strategy.; 2023.
Torsæter M., Bello-Palacios A., Borgerud L.K., Nygård O.-K., Frost T.K., Hofstad K.H, and Andrews J.S., Evaluating Legacy Well Leakage Risk in CO_2 Storage, GHGT-17, Oct. 2024, Calgary, Canada.

[8] Vielstädte L, Linke P, Schmidt M, Sommer S, Haeckel M, Braack M, et al. Footprint and detectability of a well leaking CO2 in the Central North Sea: Implications from a field experiment and numerical modelling. International Journal of Greenhouse Gas Control. 2019;84:190-203.

[9] Vulnerability is related to the likelihood that a population, community or habitat will experience substantial alteration from short-term or chronic disturbance, and to the likelihood that it would recover and in what time frame.

[10] Havtil CO2 Blowout considerations, https://www.havtil.no/contentassets/9b77c8de198b49afb887f9688b45f4be/havtil_co2-blowoutconsiderations_techncialnote_2024-380.pdf

[11] Marius Dewar, Jerry Blackford, Tony Espie, Sarah Wilford, Nicolas Bouffin, Impact potential of hypersaline brines released into the marine environment for CCS reservoir pressure management, International Journal of Greenhouse Gas Control, Volume 114, 2022.

[12] Buoyancy and/or pressure difference that can drive leakage.

[13] EC, Guidance document 1, CO2 storage life cycle and risk management framework, Section 4.2.

Balancing risk and benefits

The guidance document to the CCS Directive on 'CO_2 storage life cycle and risk management framework' further introduces the following principle[14]:

> The risk of negative impacts of CO_2 geological storage activities to human health or the environment should not outweigh the expected benefits to the social good, including from the emission reductions obtained.

This is similar to comparing biodiversity impacts against impacts on other societal interests, see e.g. Chapter 11 in the guidance document to the Biodiversity law, Chapter II - General rules on sustainable use[15]. Operators should therefore also evaluate if the aggregate risk profile for the project does not outweigh the project benefits.[16] When applying this principle to determine significance of legacy well leakage risk, a key implication is that the legacy well leakage risk must be offset by the benefit of increased stored volumes that is achieved by exposing each well to effects from the CO_2 geological storage project.

4.Proposed acceptance criteria

Risk of leakage from P&A legacy wells should be considered insignificant, i.e. acceptable without taking measures to strengthen the well's integrity, if both of the following conditions are met:

- Combination of likelihood and HSE impact is 'low' in project specific circumstance.
- Added HSE risk is offset by the benefit of (increased) stored volumes.

5.Considerations for further risk reduction

There may be opportunities to reduce legacy well leakage risk by well intervention, also when the risk is evaluated to be insignificant. However, this should only be required if

- there is a high likelihood that the well intervention will be successful (i.e. improve the barrier status without causing unpredicted environmental impacts), and
- the cost, practicality and HSE impacts of well intervention are not disproportionate to the expected additional risk reduction, and well intervention has a net environmental benefit.

[14] EC, Guidance document 1, CO2 storage life cycle and risk management framework, Section 4.1.
[15] https://www.regjeringen.no/contentassets/76ba044f8515433c93c259e7e86420f4/t-1554.pdf
[16] EC, Guidance document 1, CO2 storage life cycle and risk management framework, Section 4.2.4.