**KEM Research Question (max. 4 pages + annex)**

**TITLE** ***Monitoring requirements for $CO_2$ storage sites on the Dutch Continental Shelf***

**Objective**

The objective of this proposal is to provide guidance to $CO_2$ storage operators, the competent authority and supervisory bodies regarding best practice monitoring plans for $CO_2$ storage in offshore depleted gas fields and saline aquifers. The work should include detailed technical analysis of available monitoring tools and techniques, and the most appropriate means of applying them as part of an integrated risk management system for storage sites. The evaluation of the monitoring tools should also include potential innovations that as of yet cannot be considered best practice, but show promise with regards to their application in $CO_2$ storage activities.

The monitoring applications covered should include, but not necessarily limit to, tools for assessing conformance, well integrity and leakage detection. A clear distinction should be made between monitoring strategies under normal operating conditions, and additional contingency monitoring in case of deviations from modelled behaviour. The monitoring strategies should specify baseline monitoring, monitoring during injection, post-closure and long-term monitoring after storage permit relinquishment.

Where multiple monitoring techniques can be considered, an evaluation should be made of the foreseen benefits and disadvantages of each. The approximate costs and list of suppliers should be provided for each type of monitoring tool and instrumentation. The monitoring strategies should be tailored to the specific requirement of $CO_2$ storage in depleted fields as well as saline aquifers, and include consultation with (potential) storage operators, oil and gas service providers, the competent authority (EZK) and supervisory bodies (SodM).

**State of the art, background**

Monitoring is a key activity in the implementation of a $CO_2$ storage project. Monitoring is essential to assess whether injected $CO_2$ is behaving as expected, whether any migration or leakage occurs, and whether any identified leakage is damaging the environment or human health. A site-specific monitoring plan must be submitted by any project developer during the application for a geological $CO_2$ storage permit. The requirements of $CO_2$ storage permits and monitoring plans for $CO_2$ storage projects in Europe are covered by a limited number of national, international and European legislative acts.

The applicable regulation for the monitoring of $CO_2$ storage sites does not prescribe the use of specific monitoring tools and techniques but requires the operator to apply the prevailing 'best practice' at the time of operation. So far there is limited experience in the monitoring of $CO_2$ injected into depleted gas fields. Monitoring of $CO_2$ injection has taken place at the K12-B gas field in the Netherlands, where primarily pressure and temperature were monitored, but also tracers were used. In this case the amount of $CO_2$ injected was relatively small (80 $ktCO_2$). While the K12-B project can be considered a success, the scale of the project and the injection strategy (low pressure gas phase) is not comparable to the planned large-scale $CO_2$ storage projects which will involve high-pressure (liquid) $CO_2$ injection. There have been monitoring plans developed for the P18-4 gas field in the Netherlands, and also the Goldeneye gas field in the United Kingdom, however these projects have as yet not been implemented. In addition, $CO_2$ storage operations in saline aquifers, both onshore and offshore, as well as $CO_2$ enhanced oil recovery operations have already been performed (e.g. Sleipnir and Snøhvit in Norway) and can therefore provide useful insights into appropriate monitoring techniques. Moreover, there are expected to be a number of tools and techniques developed for conventional oil and gas production which can be adjusted/adapted for application in $CO_2$ storage projects.

Both a lack and a shortage of 'best practices' for monitoring of injected $CO_2$, for depleted gas fields and saline aquifers respectively, may lead to delays during the permitting process. This work is

therefore particularly important for the competent authority in assessing whether a monitoring plan submitted as part of a $CO_2$ storage license application is fit for purpose. Accordingly, a comprehensive evaluation of the efficacy as well as the associated costs of different monitoring tools, will assist with determining effective and balanced monitoring plans which do not lead to excessive costs to the operator.

**Research Question**

**Task 1: Technical review of monitoring tools and techniques**

Conduct a comprehensive technical review of the range of potentially suitable monitoring tools and techniques for $CO_2$ storage in depleted offshore gas fields and saline aquifers. The review should include market ready and high-Technology Reading Levels ≥TRL6[1]) monitoring techniques, covering the purpose, application, costs and benefits. A distinction should be made between conformance monitoring, well integrity and leakage detection, including seabed, environmental and leakage quantification monitoring. Seismic monitoring tools and techniques should be included. Where innovative monitoring techniques are to be considered, recommendations on future R&D actions and testing should be given.

**Task 2a: Recommendations for monitoring plans in depleted gas fields**

Based on the findings from Task 1, recommendations should be made for appropriate monitoring plans for $CO_2$ storage activities in depleted gas fields offshore. In addition to a 'base-case' monitoring plan, a set of hypothetical, but realistic storage site risks (or site non-conformance) should be provided, for example the monitoring of legacy wells, spill-points, potential fault reactivation, induced or triggered seismicity and suspected leakage to the marine environment. Distinctions should be made between standard operation and contingency monitoring, and between the baseline, injection, post-closure and long-term monitoring requirements. Moreover, the report should include a scenario that includes offshore wind turbines and related infrastructure (e.g. cables, substations) above or close to a $CO_2$ storage site, taking into account the additional risks and operational limitations this might pose (see Fugro report). Total cost indications should be given for each of the proposed monitoring plans.

**Task 2b: Recommendations for monitoring plans in saline aquifers**

Due to potentially larger uncertainties in the containment of $CO_2$, separate recommendations should be made for appropriate monitoring plans for $CO_2$ storage activities in offshore saline aquifers. Similar to Task 2a, a 'base-case' monitoring plan as well as a set of hypothetical, but realistic storage site risks (or site non-conformance) should be provided. Distinctions should be made between standard operation and contingency monitoring, and between the baseline, injection, post-closure and long-term monitoring requirements. Moreover, the report should include a scenario that includes offshore wind turbines and related infrastructure (e.g. cables, substations) above or close to a $CO_2$ storage site, taking into account the additional risks and operational limitations this might pose (see Fugro report). Total cost indications should be given for each of the proposed monitoring plans.

**Deliverables expected**

- Report on Task 1 (M7)
- Report on Task 2 (M11).

**Timeline**

Milestones:

- Project kickoff meeting (M1)
- Project inception report (M1)
- Project progress meeting (M4)
- Task 1 review meeting (M8)
- Task 2 review meeting (M11)
- Final project presentation (M12)

[1] TRL6 refers to a technology that has been demonstrated in a relevant environment

**Expected use**

The final documents will be used in discussion between storage operators, the competent authority and supervisory bodies for the identification of appropriate monitoring plans for $CO_2$ storage sites. Recommendations on innovative technologies will be used in policy developments by the competent authority to target R&D developments through policy intervention.
The deliverables/reports will be open-access; publication of project results is encouraged.

**Expertise and tools preferred for the team**

The team should have practical experience with offshore activities for example with the production of oil and gas, and preferably, $CO_2$ storage activities. The team should be familiar with the instrumentation used for controlling offshore activities, including pressure, temperature monitoring, seismic surveys, well integrity monitoring and seabed monitoring techniques. The team should be familiar with the legal requirements for monitoring plans for $CO_2$ storage, in particular the EU Directive on the geological storage of $CO_2$ 2009/31/EC. The team should also be familiar with risk management assessments. A consortium of companies and research institutes may be necessary in order to acquire the relevant expertise.

**Quality assurance, Organisational and communication requirements**

Clear work-breakdown-structure, Gantt charts, Three-months meeting, intermediate progress reports including critical issues and solution/management strategies, multidisciplinary approach and will communicate and collaborate with other experts. Additionally, the work should be reviewed by an independent reviewer team, organised within the project.

**Remarks and Suggestions**

None

**References**

No limit (reference list of papers, tools and reports)


- Bacci, V.O., O'Brien, S., Frank, J., Anderson, M., 2017. Using a Walk-away DAS Time-lapse VSP for CO2 Plume Monitoring at the Quest CCS Project. Shell Canada, Calgary, Canada.
- European Commission, 2016. Commission Opinion of 20.1.2016 on a draft permit for the permanent storage of carbon dioxide in the depleted Goldeneye gas condensate field located in blocks 14/28b, 14/29a, 14/29e, 20/3b, 20/4b and 20/4c on the United Kingdom Continental Shelf, in accordance with Article 10(1) of Directive 2009/31/EC of 23 April 2009 on the geological storage of carbon dioxide. C(2016) 152 final, Brussels.
- Harris, Kyle, Don White, Dave Melanson, Claire Samson, and Thomas M Daley, 2016. "Feasibility of time-lapse VSP monitoring at the Aquistore CO2 storage site using a distributed acoustic sensing system." International Journal of Greenhouse Gas Control, 2016: 248-260.
- IEAGHG; Review of Offshore Monitoring for CCS Projects; 2015/02. July, 2015
- Mikunda, T & Dixon, T. 2017. Review of Project Permits under the London Protocol – An Assessment of the Proposed P18-4 CO2 Storage Site. Energy Procedia, 2017, V.114, 7431-7442
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- Fugro; Safety Study CCS and offshore wind farms (2022) - Project Technical Outline. Commissioned by Ministry of Economic Affairs and Climate Policy.