OFFSHORE NORGE

Input to GD 2:
Characterisation of the Storage Complex, CO_2 Stream Composition, Monitoring and Corrective Measures

24th Feb 2023

Overall comments:

- GD2 is quite a lengthy document, hard to read, without clear recommendations. The GD2 revision should aim to shorten and streamline the document.
- There is a need to update the document with up-to-date references
- The CO2 storage complex needs to be defined up front as some issues arise from the lack of clear definition of the storage complex.
- CO2 storage in "unconventional" reservoirs such as basalts, ultramafics, coal beds does not necessarily necessitate a seal/reservoir pair as a storage complex – these might require a different (fit for purpose) site characterisation approach and process
- The conflict with other resources is a key issue, which warrants a specific focus as part of the risk assessment
- GD2 could provide guidance on the assessment of impacts related to CO2 purity and P/T design conditions across the value chain espcially in the context of the CO2 hub developments involving mult-sources and multi-stores.

Reference to text in Guidance Document / general comment: A general comment to all sections in GD2, which also could apply for other GDs.
Proposed changes: The GD 2 document is silent on O&G versus CCS permitting & regulatory processes and the "correspondence" between both systems
Justification: There are cases where:

- An O&G operator could consider converting its CO2-EOR operations into pure CO2 storage
- A storage developer explores for CO2 storage under a CO2 exploration licence and finds hydrocarbons

Reference to text in Guidance Document / general comment:

All Sections

Proposed changes:

Review role of the CA.

Justification:

GD2 views the CA's role as checking the operator and work in much detail (e.g., regarding data acquisition, p.11 (text box), p. 27). Detailed and prescriptive regulations from the CA should be avoided, which is the model used in Norwegian (petroleum) industry.

Reference to text in Guidance Document / general comment:

All Sections

Proposed changes:

Use or at least to mention SRMS terminology (CO2 Storage Resources Management System).

Justification:

It should be considered to use or at least to mention SRMS terminology (CO2 Storage Resources Management System), particularly "storage resource" instead of "capacity", as the general term for the total mass to be injected. Note that CCS Directive uses "capacity", but in many meanings (system capture rate, system transport rate, system injection rate, total storage mass) which is confusing. As the CCS Directive is not being revised, these imprecise terms are there to stay. Nevertheless, the different terminology in SRMS which matures towards industry standard, should be mentioned.

Reference to text in Guidance Document / general comment: All Sections
Proposed changes: Softening requirements on leakage and use of corrective measures, e.g., that a minor leakage may be acceptable if it causes no (or minor) local damage and does not jeopardize the overall goal of massive long-term storage, and if stopping this leakage causes cost or additional risk that is larger than the gain of the corrective operation
Justification: Is leakage (after application of reasonable corrective measures) completely forbidden according to the Directive? I.e., must any leakage be stopped completely by application of corrective measures as a condition for continued injection? A strict view of "no leakage" could be interpreted from: a. Article 16 §1 (requiring corrective action in case of leakage) b. Article 3 §19 ("'corrective measures' means any measures taken to correct significant irregularities or to close leakages in order to prevent or stop the release of CO2 from the storage complex") c. Article 18, §2(b) ("the absence of any detectable leakage"). d. Note that there is no wording that mentions "reducing the leakage". This could be addressed in the GD2 in a reasonable manner.

Reference to text in Guidance Document / general comment: All Sections
Proposed changes: The DG2 document should be updated with the most recent reports, documents, information
Justification: The IEA has recently released a report on "CO2 storage resources and their development – Analysis - IEA. The UK Government has released a key report outlining Deep geological storage of carbon dioxide (CO2), offshore UK: containment certainty - GOV.UK (www.gov.uk) an up-

to-date synthesis and estimation of the containment certainty of CO2 in deep geological storage sites

Reference to text in Guidance Document / general comment:

All Sections

Proposed changes:

The GD2 document should make a reference to the CO2 Storage Resource Management System (SRMS) and its guidelines (CO2 Storage Resources Management System (spe.org)

Justification:

The CO2 storage resources management system (SRMS) provides a consistent approach to estimate storable quantities, evaluate development projects, and present results within a comprehensive classification framework

Reference to text in Guidance Document / general comment:

Section 1

Proposed changes:

Some aspects of a storage site may be able to be 'engineered' to be more favourable, e.g. the use of smart well designs

Justification:

Justifying not to fracture the reservoir purposely to increase injectivity – storage operator should be limited injection pressure below the fracture pressure

Reference to text in Guidance Document / general comment:

All Sections

Proposed changes:

Consider including an improvement to GD2 in relation to the usage of the term "fracture gradient (FG)". This term appears at many locations and also in the "glossary". In general,

Offshore Norge argues that the minimum principal stress shall be used to set pressure limits for safe injection. This is well understood in O&G well integrity departments and is the basis/common practice for safety design in Norsok D-010 for long-term well integrity with fluids other than drilling mud ("Minimum formation stress/fracture closure pressure (FCP) shall exceed the maximum wellbore pressure at formation depth). FG is not uniquely defined in the drilling discipline. Indeed, FG is a system property that depends upon many factors such as fluid rate, fluid rheology, particle content, hole size, temperature, and more. Minimum principal stress is a bulk formation property which is a measurable, consistent, and robust barrier requirement. This is described in our publications: ARMA 22–559 and ARMA 2016-887.
Justification: Clarify and improve on usage of the term "fracture gradient (FG)" in the GD2.

Reference to text in Guidance Document / general comment: p. 20, Section 1.3.3
Proposed changes: (additions in red) The latter style of trapping, which has been described as migration assisted storage (MAS – Bradshaw et al., 2009, Spencer et al., 2010), can be utilised where modelling indicates that the injected CO2 will not reach the surface despite not being injected into a geological structure, or which indicates that, despite being located along a migration pathway ~~from~~ (toward?) a geological structure, it will be trapped physico-chemically before reaching the geological structure.
Justification: The sentence does not make sense (to me). Besides, it is too long and deserves rewording.

Reference to text in Guidance Document / general comment: Section 1.3.4
Proposed changes:

In general, DG2 should cover recent relevant CO2 storage developments. Guidelines should be adapted to these kind of storage options.
Justification: Guidance document 2 should address recent relevant developments. As an example there is a focus on Coal Bed Methane as an alternative option. Following the deployment of Basalt storage by Carbfix, a focus could be made on Basalt storage as well.

Reference to text in Guidance Document / general comment: Section 1.4 (Initial Assessment at Regional/Country Level)
Proposed changes: Under the CCS Directive, the term "exploration" refers to an assessment of potential storage complexes by means of activities intruding into the subsurface such as drilling to obtain geological information about strata in the potential storage complex. Exploration should also include seismic acquisition & reprocessing Exploration might also include injection tests in order to characterise the storage site. Injection tests are part of exploration (and appraisal) work program as well as other well testing
Justification: Include seismic in the definition of “exploration”. Include dynamic well test (includng injection tests).

Reference to text in Guidance Document / general comment: Pages 26-27, 1.5.1 Storage Complex: "Questions will arise …"
Proposed changes: Reword or remove paragraph from "Questions will arise …" to “…what constitutes the storage complex.”
Justification:

This paragraph, and a few occasions later in the GD2, suggests the whole volume in which pressure increases (the pressure footprint) and/or in which formation water is displaced, as (potential) part of the storage complex. However, Article 8, §1(c) implies that the pressure footprint extends beyond the storage complex/license boundaries.

Reference to text in Guidance Document / general comment:

Pages 27, 1.5.1 Storage Complex: "As CO2 dissolves in the formation water, it becomes heavier and could move further down dipinto the basin, and therefore, any associated geological attributes or features of a geological formation where the CO2 plume may actually reach could also be considered as part of the storage complex"

Proposed changes:

Remove “could also be considered as part of the storage complex” and include a comprehensive definition of storage complex.

Justification:

According to this interpretation, the whole subsurface volume that may be reached by CO2 dissolved in formation water and sinking down (or being moved by subsurface regional flow) should be included in the storage complex. This is not the interpretation presently applied in Norway.

Reference to text in Guidance Document / general comment:

Page 28, 1.6.2 Collection of Additional Data and Processing of Site-level Data

“sufficient data needs to be accumulated to construct a volumetric and three-dimensional static (3-D)-earth model for the storage site and storage complex, including the caprock, and the surrounding area, including the hydraulically connected areas”

Proposed changes:

Should specify: including hydraulically connected areas when potential interference with neighbouring resources may occur.

Justification:

Must these hydraulically connected areas (in essence: the pressure footprint) be explicitly included in the model (which implies that it will become very large) or can they be included implicitly, e.g., as a numerical aquifer.

Reference to text in Guidance Document / general comment: Section 1.6.1 (Compile and Evaluate available existing data)
Proposed changes: Data sources of prime use will include information from oil and gas fields, both exploration and production, any deep stratigraphic drilling and any other wells penetratring the storage complex that has taken place.
Justification: Data should not be limited to only O&G wells. Water wells can provide relevant data as well as geothermal and other energy storage wells

Reference to text in Guidance Document / general comment: Page 31, 1.6.2.5
Proposed changes: The chapter on geomechanics tackles only pressures. It needs to be more general, at least by naming also stress related to temperature variation
Justification: It needs to name also temperature as it is likely to play a significant role in CO2 injection, potentially more so when depths are significant, and at least in the near wellbore area

Reference to text in Guidance Document / general comment: Page 32, 1.6.2.6 Seismicity: "There is a world wide array… …is well understood and documented."
Proposed changes:

Remove sentence.

Justification:

This formulation may give the wrong impression that this array can be used to localize earthquakes (incl. induced seismicity?) precisely enough to be sure that they are within a storage site or not.

Reference to text in Guidance Document / general comment:

Page 34, 1.6.2.11 Interactions with other Sub-surface Activities: "…CO2 injection could increase regional reservoir pressure and actually benefit oil and gas production…"

Proposed changes:

Negative impact of different CO2 storage projects in the same hydraulic unit on each other should be mentioned, i.e., that CO2 storage capacity for one project might be reduced by pressure increase in the hydraulic unit caused by injection of CO2 in another storage project, and vice-versa.

This chapter should also mention potential conflicts of usage of surface above the storage site, e.g., offshore wind installations, affecting ability to monitor the site by 4D seismic.

Justification:

CCS directive (Article 8 1c)) refers to pressure in hydraulic units, but it is not clear in the GD2 the negative impact of different storage projects in the same hydraulic unit on each other. Pressure increase in one storage site may cause pressure increase in another one with which it is in hydraulic communication, thus potentially limiting CO2 storage capacity for each other.

Reference to text in Guidance Document / general comment:

Page 33 Section 1.6.2.7 "... and DST and RFT analysis"

As well as Page 39, Section 1.7.6

Proposed changes:

"... and pressure measurement analysis"

Justification:

No reason to name specific tools, the sentence should remain generic.

Reference to text in Guidance Document / general comment:

Section 1.6.2.11 (Interactions with other Sub-surface activities)

Proposed changes:

The CO2 plume could reduce the pore space available for natural gas storage reservoirs and other reservoirs targeted for energy storage

Justification:

Natural gas storage is not the only related energy storage, which could be impacted by CO2 Storage

Reference to text in Guidance Document / general comment:

Page 37 Section 1.7.2 Well Correlation

Proposed changes:

Introduce pressure measurements analysis, it is missing!

Justification:

In establishing fluid flow units or fluid flow barriers, analysis of pressure measurements (when available) along with well correlations is best practice.

Reference to text in Guidance Document / general comment:

Page 39 Section 1.7.6 Seal thickness, Extent and Capacity

Proposed changes:

Introduce also the notion of semi-quantitative (not only qualitative) assessment of seal/barrier capacity.

Justification:

If pressure data are available near or at the site, quantitative assessment of the default seal capacity of a fault or a caprock may be carried out (buoyancy pressure, transformed in equivalent of fluid column height)

Reference to text in Guidance Document / general comment:

Page 40 Section 1.7.7 Migration Pathways

Proposed changes:

"The storage fairway ~~is~~ can be predicted based on"

Justification:

English

Reference to text in Guidance Document / general comment:

Page 41, 1.7.10 Geochemistry: "... formation water sampling … build this into the geological model."

Proposed changes:

Remove "build this into the geological model".

Justification:

This is not usual. Standard geological models do not cover geochemistry.

Reference to text in Guidance Document / general comment:

Page 43, 1.8.3 Recalibrating modelling based on operational and monitoring data: first sentence: "… behaviour predicted in the dynamic simulation of the 3D model". Also valid for several other mentions of "model" in the GD2.

Proposed changes:

Change from “predicted in the dynamic simulation of the 3D model” to “predicted in the 3D dynamic simulation modelling process”

Justification:

The reader might view "the model" as a single realization/case of the subsurface, not as a set of models that cover uncertainty. Such uncertainty is mentioned in other places in the GD. However, maybe it should be explicitly explained somewhere that term "the model" encompasses a whole set. This is important for the comparison of monitoring data with predictions. Key is that the observations are within the range of predictions from the set.

Reference to text in Guidance Document / general comment:

Page 44, 1.8.3 Recalibrating modelling based on operational and monitoring data: first full paragraph in that page "The second most important …"

Proposed changes:

This should be reformulated such that it does not make impression that monitoring wells is a must, but only an option.

Justification:

Too much focus on monitoring wells compared to seismic data. Monitoring wells provide very local information that has little value without 4D seismic, whereas 4D seismic can provide much value even without monitoring well data.

Reference to text in Guidance Document / general comment:

Section 2 – CO2 Stream

Proposed changes:

Contaminants in CO2 can generally be divided into 3 categories:

- Contaminants that can have an impact on corrosion such as O2, H2O, NOX, SOX, Glycol, Hydrogen (can cause embrittlement)
- Contaminates that are human safety concern including CO, NOX, SOX, Hg. These contaminants need to be considered from a short term exposure perspective in the event of containment failure perspective in CCS projects

- Contaminants that could affect the physical properties of the CO2 stream, which include:.
    - H2O - Risk of Hydrates – note that in general if H2O is low enough to avoid corrosion, then hydrates are not expected
    - Inert gasses - impact on vapour pressure in the case of liquid phase and impact on critical pressure in the case of dense phase
    - Non-Corrosive Components that could precipitate as liquids – leading to flow assurance problems.
    - Non-Corrosive components that could freeze and cause blockage issues.

Justification:

Better describe the categories of contaminants

Reference to text in Guidance Document / general comment:

Section 2 – CO2 stream

Proposed changes:

CO2 purity threshold for each contaminant should be a function of both operating conditions of CO2 transport and storage and may require modification on a project by project basis

Justification:

Lack of good understanding where some limits for CO2 specs come from, without assessing the basis for each limit on a case by case basis and without performing a detailed assessment of what the maximum allowable value might be.

For instance, oxygen is one of the most expensive contaminants to meet. Especially for gas/dense phase export cases, this requires oxidative removal. The limit (often set at 10ppm) could be generally increased without any HSSE impacts

Impacts from impurities in the CO2 stream can also vary depending on the operating conditions

Reference to text in Guidance Document / general comment:

Section 2
Proposed changes: CO2 purity threshold for each contaminant may require risk assessment on project by project basis however will require guidance on CO2 specifications for CCS projects.
Justification: CS projects will benefit from P/T and CO2 purity standardisation.

Reference to text in Guidance Document / general comment: Page 58, 2 Composition of CO2 Stream
Proposed changes: This chapter can be improved by mentioning other means of CO2 transport and that CO2 stream composition must be compatible with requirements of the means it is transported with, i.e., pipeline or bulk transport (ships, trucks, trains, barges). Each of these means might have different requirements. Reference should also be made to recently published ISO standard on CO2 stream composition ISO/TR 27921:2020 (Carbon dioxide capture, transportation, and geological storage - Cross Cutting Issues - CO2 stream composition) and to paying attention to any new developments within this topic that are expected in the future.
Justification: Other means of transport than pipeline should be clearly stated as the CO2 stream composition must be compatible with them, and the requirements might differ from each other.

Reference to text in Guidance Document / general comment: Page 48, 2.9.1 Hazard Characterization; Fault and Seal Integrity
Proposed changes:

1. Distinguish between across-fault and along-fault flow. For the former, there are (semi-) quantitative methods established and applied in industry and academia; for the latter, methods for quantification are still rudimentary.
2. Fault smear and shale gauge should be mentioned as processes that make a fault less permeable than it was prior to displacement.
3. It could be added, that in many cases, particularly in many offshore settings, the vertical extent of faults is limited and they do not extend to the surface but are capped by rock sequences which often contain seal layers. Therefore, migration of CO2 along such faults does not automatically lead to leakage to the sea or atmosphere.

Justification:

More clarification on fault properties.

Reference to text in Guidance Document / general comment:

Page 49-50, 1.9.1 Hazard Characterization; Geochemical evaluation of new substances

“Geochemical assessment of both the groundwater and…”

“This will require sampling of the…”

Proposed changes:

Change “groundwater” to “reservoir water”.

Justification:

"Groundwater" may wrongly be interpreted as this sentence only or mainly applying to shallow, water-bearing layers (potable water?). If the likelihood for migration to levels of potable water is very low, the balance between reasonable costs and value of results of such sampling of the formation water may not defend the sampling.

Reference to text in Guidance Document / general comment:

Page 76 (1st text box on the page), 2.7 Storage integrity: “Hence, it is important for operators to conduct geochemical analyses…”

Proposed changes:

Remove the text box.

Justification:

Due to lateral and vertical variability of the seal rock lithology samples of rock and local formation water will not be fully representative. Many reactions may happen much slower than what can be observed at mimicked in-situ conditions in the lab. Acquisition of samples (most logical would be from a part of the storage site that will contain CO2) during and after the injection would be costly and would potentially increase leakage risk, since it involves a new man-made penetration of the seal. Further, advance of CO2-rich fluid in the caprock (and transport of reaction products) will be slow, primarily by diffusion. Thus, reaction-transport modelling may provide more relevant answers than geochemical lab experiments.

Reference to text in Guidance Document / general comment:

Section 3.3.1 , Table 11 " Summary of Possible Monitoring Methods and Applicability"

Proposed changes:

Large applications of Fiber Optics are already done and envisaged and as such this could be added to the list of monitoring methods.

Justification:

Guidance Document 2 should reflect recent advances in monitoring technology.

Reference to text in Guidance Document / general comment:

The pressure impacts and pressure interferences between various uses of the subsurface (including various CO2 Storage projects) in the same formation are not tackled by the Guidance Documents 1 & 2. Although the EU CCS directive has four mentions of hydraulic connections In Article 3, Article 9, Annex 1/Step 1 and Annex 1 /Step 2, GD2 only describes the static and dynamic modeling of the storage site and complex, referring to surrounding area, with no insight on how to account for pressure interactions within a given hydraulic unit.

- Page 28 of GD 2: As specified in Annex I of the CCS Directive sufficient data needs to be accumulated to construct a volumetric and three-dimensional static (3-D)-earth model for the storage site and storage complex, including the caprock, and the surrounding area, including the hydraulically connected areas. This data shall cover at least the intrinsic characteristics of the storage complex that are discussed in the following subsections.
- Page 36 of GD 2: Building the three-dimensional static geologic earth model is represented as Step 2 in Annex 1 of the CCS Directive. Step 2 consists of using the data collected in Step 1 to construct one or more three-dimensional static geological earth models of the potential storage complex, including the caprock and the hydraulically connected areas and fluids.
- However pressure evolution within the hydraulically connected area is only marginally described in section 1.8 (subsection 1.8.4) or Table 1 with no comment of potential interferences between operators.
- Page 9 has a very strong statement which is not elaborated further: Each site will need to be assessed individually in terms of local impact on fracture gradients (see Glossary below), but if there is regional hydraulic communication, there will need to be consideration of how the basin pressure system is managed at a regional level.
- Page 34 – section 1.6.2.11 – Interaction with other subsurface activities: The focus is almost explicitly on CO2 migration with minor statements on pressure impacts

Proposed changes:

Outline how to practically evaluate the risks of pressure interferences, how the CA could anticipate the issue when making acreage available for licencing and how technical and legal challenges could be addressed should be included in GD1 & GD2.

Justification:

Modeling hydraulic areas as part of the 3D model is highly challenging, as they can cover a significant fraction of the North Sea for some aquifers (Utsira in Norway, Gassum in Danemark, Bunter in UK for example) and contain various users (geothermal, other CCS project, HC production) with unknown current or future injection / extraction activities. Further, storage sites with possible pressure connection challenges either to third party activity (geothermal activity) or between different CO2 storage licences have been identified.

Reference to text in Guidance Document / general comment:
Generally comprehensive and good description of monitoring aspects. One topic to discuss: "It is therefore important that the choice of monitoring technology shall be based on best practice available at the time plans are formulated or updated, but not based on what might emerge in the future. The cost effectiveness of specific technologies may be considered when monitoring plans are developed."
Proposed changes:
The cost effectiveness of specific technologies **shall** be considered when monitoring plans are developed.
Justification:
Cost efficiency and caution with O&G standards should be a major concern for storage complex monitoring.

Reference to text in Guidance Document / general comment:
Chapter 3.2, last box before chapter 3.2.1, page 92: The cost effectiveness of specific technologies may be considered when monitoring plans are developed.
Proposed changes:
The cost effectiveness **and environmental impact minimisation** of specific technologies **shall** be considered when monitoring plans are developed.
Justification:
Monitoring solutions should be optimised for environmental impacts

Reference to text in Guidance Document / general comment:
Coupled process modelling is mentioned at several occasions
Proposed changes:
Add: when necessary

Justification:

Might not be required for all projects

Reference to text in Guidance Document / general comment:

"Understanding the geochemistry of a site will benefit from injection tests prior to final approval and use of core samples from the site in laboratory tests that mimic the subsurface conditions."

Proposed changes:

The geochemistry of a site and its potential injectivity impairment should be evaluated and mitigation methods considered.

Justification:

Appears too specific.

Reference to text in Guidance Document / general comment:

Page 106, 3.4.2 and 3.2.3:
Defining the Monitoring Area (text box): “The monitoring area should include the injection facilities, the storage complex (including where possible the CO2 plume),…”

Proposed changes:

The monitoring area should include the injection facilities, part of the storage complex where the CO2 plume is expected to be present, …

Justification:

Monitoring does not need to cover the whole storage complex, at least not initially. The storage complex can be much larger than the reasonably expectable extent of the CO2 plume during the initial years of injection. The size of the storage complex may be defined by the expected final extent of the plume.

Reference to text in Guidance Document / general comment:

Page 105, 3.3.7 Performance Standards
Proposed changes: Remove the chapter or be more specific on what these performance standards would be.
Justification: A vague description of "performance standards" and their use. What these performance standards would be. There are no examples of those.

Reference to text in Guidance Document / general comment: Page 130, 4.3 Responsibilities during project phases: “the CO2 plume is expected to be stable.”
Proposed changes: Suggest changing this text to be in line with the Directive text, which is better reflecting reality, i.e., “as the site is evolving towards a situation of long-term stability.”
Justification: The formulation is stricter than the requirement according to Article 18 §2(c) of the CCS Directive: "that the storage site is evolving towards a situation of long-term stability."

Reference to text in Guidance Document / general comment: General comment
Proposed changes: Outline CA area for support and interaction with CO2 storage projects
Justification: Early and continuous engagement with the CA is an important contributor to storage project success, but there should be a limitation on how much CA is allowed to interfere with the projects.

Reference to text in Guidance Document / general comment:
General comment
Proposed changes:
CA should act as a facilitator of dialogue between existing and new project in case of potential conflicts due to ongoing or planned activities (e.g., infrastructure construction)
Justification:
Existing projects should have right to object to actions impacting their activities

Reference to text in Guidance Document / general comment:
General comment
Proposed changes:
Functional requirements for storage operations should be clearly defined by CA, but there should be a room for updates based on operational experience.
Justification:
Need for functional requirements to be formulated by CAs