Technology Collaboration Programme
by iea

IEAGHG Technical Report
2022-11
September 2022

Applying ISO Standards to Geologic Storage and EOR Projects

IEA GREENHOUSE GAS R&D PROGRAMME

International Energy Agency

The International Energy Agency (IEA), an autonomous agency, was established in November 1974. Its primary mandate was – and is – two-fold: to promote energy security amongst its member countries through collective response to physical disruptions in oil supply, and provide authoritative research and analysis on ways to ensure reliable, affordable and clean energy for its 30 member countries and beyond. Within its mandate, the IEA created Technology Collaboration Programmes (TCPs) to further facilitate international collaboration on energy related topics. To date, there are 38 TCPs who carry out a wide range of activities on energy technology and related issues.

DISCLAIMER

COPYRIGHT

ACKNOWLEDGEMENTS AND CITATIONS

This report describes describes work undertaken by DNV on behalf of IEAGHG. The principal researchers were:

- Jorg Aarnes
- David Buchmiller
- Embla Larsdotter Holten

To ensure the quality and technical integrity of the research undertaken by IEAGHG each study is managed by an appointed IEAGHG manager. The report is also reviewed by a panel of independent technical experts before its release.

The IEAGHG manager for this report was Samantha Neades.

The expert reviewers for this report were:

- Sean Brennan, USGS
- Carl Greenfield, IEA
- David Khoza, Geoscience Council, South Africa
- Jordan Kislear, US DOE
- Filip Neele, TNO
- Katherine Romanak, GCCC, BEG at University of Texas
- Bob van Voorhees, Independent Consultant
- Steve Whittaker, Illinois State Geological Survey

The report should be cited in literature as follows: : 'IEAGHG, "Applying ISO Standards to Geologic Storage and EOR Projects", 2022-11, September 2022.'

Further information or copies of the report can be obtained by contacting IEAGHG at:
IEAGHG, Pure Offices, Cheltenham Office Park
Hatherley Lane, Cheltenham,
GLOS., GL51 6SH, UK

Tel: +44 (0)1242 802911
E-mail: mail@ieaghg.org
Internet: www.ieaghg.org

APPLYING ISO STANDARDS TO GEOLOGIC STORAGE AND EOR PROJECTS

(IEA/CON/21/276)

The work aims to summarise and synthesise the two ISO Standards relevant to the geological storage of CO_2: – ISO 27914:2017 (‘Carbon dioxide capture, transportation and geological storage - Geological storage’) and ISO 27916:2019 (‘Carbon dioxide capture, transportation and geological storage - Carbon dioxide storage using enhanced oil recovery (CO_2-EOR)’) – to provide a high-level understanding of the content into an easily digestible format. By comparison with international regulatory frameworks, and providing case studies of how applicable the standards are to real CO_2 storage projects, the study provides a comprehensive overview and concludes on the usefulness of the documents in supporting the implementation of CCUS projects. For the purposes of this overview, the standards will hereafter be referred to as ISO 27914 and ISO 27916.

Key Messages

- Both standards relevant to the geological storage of CO_2, ISO 27914 and ISO 27916, are complementary with minimal overlap, as was intended by stakeholders.
- ISO 27914 is intended for projects with the sole purpose of CO_2 storage:
    - The objective being ‘to commercial, safe, long-term containment of carbon dioxide in geological systems in a way that minimises risk to the environment, natural resources, and human health’.
- ISO 27916 is intended to apply to CO_2-EOR projects:
    - With the objective of promoting ‘the use of geologic storage associated with CO_2-EOR by providing a common process for assuring safe, long-term containment and for quantifying and documenting the amount of CO_2 that is stored in association with CO_2-EOR’.
- Both standards can be used to evaluate and guide key technical areas of storage projects, including site feasibility, well re-qualification and developing risk-based monitoring and verification programmes.
- Both standards provide limited specific support for requirements related to approval processes, ownership, government roles, subsurface ownership regime, and transport.
- Both standards support (in general) CO_2 stream definition, leakage accounting, MMV, storage and siting, closure, public engagement and risk assessments.
- Elements of ISO 27914 can provide guidance for CO_2-EOR projects, even though it is not explicitly intended for such use.
- There is a similarity between regulatory regimes for oil and gas projects and CO_2 storage projects and therefore existing petroleum regimes, complemented by the ISO standards, could be combined to form a specific regulatory regime for the geological storage of CO_2.
- Five examples are provided from developing economies with an oil and gas industry to show that regulations pertinent to CO_2 storage are either established or require refinement from pre-existing oil and gas regulations or need to be fully developed.
- The ISO standards are an evolving entity and subject to refinement and continuous updating where deemed necessary (ISO operate a 5-year review cycle on all published standards). Some experts have recognised that ISO standard 27914:2017 may be difficult to implement for real projects due to the large number of requirements, and suggest this standard could be seen as more of a best practice guide.

Background to the Study

The International Standards Organization (ISO) has published standards for the geological storage of CO_2, 'Carbon dioxide capture, transportation and geological storage — Geological storage' (ISO Standard reference number 27914:2017) and 'Carbon dioxide capture, transportation and geological storage — Carbon dioxide storage using enhanced oil recovery (CO_2-EOR)' (ISO 27916:2019). The standards provide a sound basis for demonstrating and / or quantifying that CO_2 is safely stored long-term within permeable and porous geological strata including hydrocarbon reservoirs where a CO_2 stream is not being injected for the purpose of hydrocarbon production and for storage in association with CO_2-EOR.

The first standard specifically related to the geological storage of CO_2, 'Carbon dioxide capture, transportation and geological storage — Geological storage', (ISO 27914:2017) was published in October 2017 and establishes requirements and recommendations for the storage of CO_2 streams, to promote commercial, safe, long-term containment of CO_2 whilst minimising risk to the environment, natural resources, and human health.

This standard is applicable for onshore and offshore storage within permeable and porous geological strata including hydrocarbon reservoirs where a CO_2 stream is not being injected for the purpose of hydrocarbon production or enhanced oil recovery. The document includes activities associated with site screening and selection, characterisation, design and development, storage site operation and preparation for site closure. Monitoring, verification and the recognition that site selection and management are unique for each project highlights the intrinsic technical risk and uncertainty and the necessity for site-specific assessment. It acknowledges that permitting and approval by regulatory authorities will be required throughout the project life cycle, including the closure period (although the permitting process is not included). It provides requirements and recommendations for the development of management systems, community and other stakeholder engagement, risk assessment and management, and risk communication.

This standard does not apply to, modify, interpret or supersede any national / international regulations, treaties or protocols otherwise applicable to the activities in the standard. Furthermore, it does not apply to or modify any property rights or interests in the surface / subsurface or any pre-existing commercial contract relating to such property. The report also describes the limits, technical and general, of the standard.

'Carbon dioxide capture, transportation and geological storage — Carbon dioxide storage using enhanced oil recovery (CO_2-EOR)' (ISO 27916:2019), published in the January of 2019, applies to CO_2 that is injected in EOR operations for which the quantification of CO_2 that is safely stored long-term in association with the CO_2-EOR project is sought. It recognises that some EOR projects use non-anthropogenic CO_2 in combination with anthropogenic CO_2 and shows how allocation ratios could be utilised for calculations of the anthropogenic portion of the associated stored CO_2.

This standard does not apply to quantification of CO_2 that is injected into reservoirs where no hydrocarbon production is anticipated or occurring but refers to the previously noted standard which covers CO_2 storage in formations that do not contain hydrocarbons (even when located above or below producing reservoirs), and also covers storage in reservoirs where hydrocarbons were previously produced but will no longer be produced in commercial / paying quantities or where the intent for storage is not to enhance recovery.

The conceptual boundary of this standard includes the safe, long-term containment of CO_2 within the EOR complex, CO_2 leakage from the complex through pathways and on-site project loss of CO_2 from wells, equipment or other facilities. The standard does not include lifecycle emissions and CO_2 emissions resulting from the combustion of the produced hydrocarbons, storage of CO_2 above ground, buffer and seasonal storage of CO_2 below ground, any technique or product that does not involve the injection of CO_2 into the subsurface, and emissions of any other greenhouse gases other than CO_2.

Scope of Work

The purpose of this study is to summarise, compare, and contrast the published ISO standards relating to the geological storage of carbon dioxide (ISO 27914:2017 and ISO 27916:2019 only) with current regulatory frameworks and provide a high-level understanding of the content of the standards into an easily digestible format.

The study begins with a synthesis and comparison of the standards with existing EU and US regulations for CO_2 storage and CO_2-EOR and looked into the applicability of supplementing the existing regulations with the standards in terms of storage site permitting and emission accounting. Case studies were used to demonstrate application of the ISO standards in real projects, looking at situations where the standards assisted in determining site feasibility for storage, re-qualification of wells at storage sites and development of a risk-based monitoring and verification plan. The study then conceptually evaluates the potential for using the standards to assist in the implementation of CCS projects in regions without tailored CCS regulations.

Findings of the Study

Synthesis and comparison with regulations

ISO 27914: 'Carbon dioxide capture, transportation and geological storage — Geological storage'

ISO 27914 is intended to establish requirements and recommendations for the geological storage of CO_2 and to help promote commercial, safe, long-term containment of CO_2 that minimises risk. This particular standard only applies to projects with geological storage for the sole purpose of storage and is applicable to both onshore and offshore sites.

The implementation and use of this standard is voluntary (except when specifically required by regulators) and can be used as a supplement to regulations. The structure of the standard broadly follows the lifecycle of a storage project: pre-injection site screening, selection, characterisation and modelling (Clause 5), well infrastructure development, maintenance and decommissioning (Clause 7); injection site operations (Clause 8), and site closure (Clause 10). It also includes clauses relevant for all stages of a project: management systems; recommendations for risk management; and a final clause pertaining to recommendations for monitoring and verification.

During the development of ISO 27914, it was acknowledged that other standards exist that are applicable to geological storage projects, for example with regards to well infrastructure. This ISO standard was intended as a standalone document with limited overlap with other publications. It specifies additional considerations that are unique to safely managing CO_2 injection and storage, and by referencing other relevant recommended practice manuals / standards.

ISO 27916: 'Carbon dioxide capture, transportation and geological storage — Carbon dioxide storage using enhanced oil recovery (CO_2-EOR)'

ISO 27916 applies to the process of quantifying / documenting the amount of CO_2 that is stored in association with CO_2-EOR and to highlight the part of the CO_2 that comes from anthropogenic emission sources. It is expected that this standard will support development of rules for accounting of greenhouse gas emissions for EOR projects. This standard also provides recommendations and requirements for demonstrating that an EOR site is adequate to provide safe, long-term containment of CO_2 and to demonstrate that the CO_2 flood will eventually remain contained in the complex. It includes recommendations for documentation and record keeping, description, qualification and construction of the complex, monitoring and provision of containment assurance, well construction and intervention, and project termination.

ISO 27916 is less prescriptive than ISO 27914 and provides more high-level guidance. A core section of the standard is on quantification, noting that it does not apply to the quantification of CO_2 injected into reservoirs where no hydrocarbon production is anticipated / occurring – excluding CO_2 storage-only projects. Some of the equations in the quantification section can be applied *in principle* to quantify the amount of CO_2 stored in storage-only projects, however. The application of ISO 27916 is also not intended for: calculation of lifecycle emissions for the full CCUS chain; for storage of CO_2 above ground; for buffer / seasonal storage of CO_2 below ground; calculation of other greenhouse gas emissions; or the selection, characterisation or permitting of sites for EOR projects.

Fundamentally, the amount of CO_2 stored is the amount injected minus the amount lost (a combination of vented CO_2 – intended release, fugitive emissions – unintended release, or CO_2 transferred from the EOR project. ISO 27916 guides on estimating the fraction of anthropogenic CO_2 (that which is initially produced as a by-product of processes where it would otherwise be emitted to the atmosphere) in the stored CO_2 and considers the possibility of including native CO_2 (CO_2 present and indigenous within the reservoir prior to production or injection). Normally, market mechanisms for storing CO_2 will only provide credits for storage of anthropogenic CO_2 emissions but operators may want to keep track of all CO_2 stored. During the development of this standard, it was recognised that regulators may have different perspectives as to whether native CO_2 should be included in emissions accounting and so the standard notes that 'produced, captured and reinjected native CO_2 may be included in the quantification of stored CO_2 if this is approved by the authority'.

Comparison Of ISO 27914 & ISO 27916

Both standards are complementary to a large degree and have minimal overlap; ISO 27914 is only applicable to projects injecting CO_2 for the sole purpose of storage and ISO 27916 only applies to CO_2-EOR projects. Although the two standards are designed to serve different purposes (to promote safe, long-term CO_2 storage only versus promoting the use of CO_2-EOR for CO_2 storage), there are elements of ISO 27914 that could provide guidance for EOR projects, namely the content in Clause 7 (well infrastructure), Clause 8 (CO_2 storage site injection operations), Clause 9 (monitoring and verification) and Clause 4 (management systems). ISO 27914 however is more prescriptive and therefore also included requirements that would be additional to what is required by ISO 27916 for CO_2-EOR, parts of ISO 27916 would also be functionally applicable to CO_2 storage (only) projects, such as Clause 8 (quantification).

The figure below provides a high-level overview of the applicability of the two standards with green signalling applicability, yellow meaning partial applicability and red indicating this area is not addressed or included in the standard.

Topic	ISO 27914	ISO 27916
Management systems	Clause 4 (+ e.g. 6.5 and 8.3)	Operations management plan, and requirements for documentation and record-keeping (Clause 4 and 9)
Risk management	Clause 6	Mentioned, but very limited guidance on how to manage risks. Mainly Clause 6.
Well infrastructure	Clause 7	Very high level, limited guidance
Operations	Clause 8	Some high-level guidance in Clause 6.1
Monitoring	Clause 9	Some high-level guidance in Clause 6.2
Site closure/Project termination	Clause 10	Clause 10
Quantification of GHG emissions		Clause 8, quantification of CO_2 stored
Permitting		
Stakeholder consultation/communication	High level guidance in Clause 4.1.3 and 4.6 + guidance on risk communication and consultation in Clause 6.10	
Environmental (impact) assessment		
CO_2 composition	Limited guidance, e.g. Clause 5.4.4	
Post closure/termination		

Figure 1. **Comparison of ISO 27914 and ISO 27916 and their applicability to CO_2 storage and CO_2-EOR projects**. (IEAGHG, 2022)

Comparison Of ISO 27914 With Existing Regulations for CO_2 Storage

ISO 27914 does not apply to, interpret or supersede any national or international regulations or protocols otherwise applicable to the activities addressed, but it does provide additional guidance on matters dealt with under regulations. The guidance may therefore be considered as useful to some regulators as part of the approval process. Generally, regulations only stipulate high-level requirements, whereas ISO 27914 provides guidance on process, materials, techniques and plans which may enable the regulatory requirements to be met with confidence.

Although there are no mandatory requirements in existing regulations to use ISO 27914, the report provides examples of regulations where specific relevance is made to the standard and also a detailed overview of relevant parts of selected regulations (US Class VI rules, EU CCS Directive and Australian Commonwealth regulations) for each of the key chapters in the standard.

Comparison Of ISO 27916 With Existing Regulations For CO_2-EOR

ISO 27916 is compared with Class II rules under the US EPA UIC Program and the reporting of CO_2 emissions stored for tax credits under the 45Q regulation. Operators in the US need to acquire a Class II well permit from the EPA (Environmental Protection Agency) and the key requirements for the permits are specified regarding well construction, operation, monitoring and reporting, and information. The report compares these requirements in detail with those in ISO 27916.

The US IRS internal revenue code section 45Q enables the application for tax credits by reporting CO_2 sequestration. Taxpayers that claim the tax credit of section 45Q must follow the appropriate UIC (Underground Injection Control) requirements for Class II or Class VI wells and follow the guideline in Subpart RR of the EPA's 40 CFR Part 98 on the geologic sequestration of CO_2. In the new rule, taxpayers operating a CO_2-EOR project can elect to report volumes of CO_2 stored pursuant to ISO 27916, provided documentation is certified by a qualified independent engineer or geologist. Both Subpart RR and ISO 27916 require annual reporting of stored CO_2 and provide mandatory calculations of CO_2 mass that is input to EOR operations and any CO_2 mass that is lost during the cycle in operations. The calculation requirements differ in the specification of what / where CO_2 input and loss are to be calculated. To the knowledge of the authors of this report, the 45Q tax regulation is the only regulatory guidance document that makes explicit mention of ISO 27916. The report summarises and compares the calculation of CO_2 mass that can be registered as stored CO_2 for ISO 27916 and Subpart RR.

Applicability to supplement existing regulations

Application Of ISO 27914 To Support Storage Site Permitting

For the geological storage of CO_2 there are broadly four different permits of relevance: an exploration / evaluation permit, a storage permit or sequestration lease, an injection permit, and a closure certificate and transfer or responsibility (if relevant in the jurisdiction). ISO 27914 does not provide explicit guidance on permitting requirements. To argue compliance with ISO 27914 at a given point in the lifecycle, as part of a permitting process, the proponent must first establish consensus with the relevant regulator on the requirements to be considered. DNV have mapped in DNV-SE-0473 requirements and recommendations in ISO 27914 to overcome this hurdle, to use this document to inform project proponents, and regulatory authorities, about the requirements in ISO 27914 that should be considered at different stages of a CO_2 storage projects. The report provides examples of how ISO 27914 can support storage site permitting using examples from Norway, which has transposed the EU CCS Directive into national law mirroring the regulation of oil and gas developments, and Alberta, which has introduced the Alberta Carbon Sequestration Tenure Regulation where specific requirements apply for the issuance of a closure certificate for the carbon sequestration lease. The study looks at how ISO 27914 provides further guidance to stakeholders that may facilitate approval of Norwegian and Albertan certificates.

Application Of ISO 27916 To Support Emission Accounting

Clause 8 in ISO 27916 established methods for the quantification of mass of CO_2 stored and lost associated with CO_2-EOR operations, specifying how native CO_2 can be included and how to determine the anthropogenic part of the CO_2 stored and emitted. With regards to the US 45Q tax regulation, operators may select to quantify CO_2 emissions stored using the methodology in ISO 27916 rather than the RR reporting rules. Both the ISO standard and RR rules are focused on quantifying the amount of CO_2 stored and not the GHG emission reductions that can be attributed to the project. As ISO 27916 allows for native CO_2 to be included (provided this is accepted by the regulator), the operator can receive increased tax credits for their CO_2-EOR operation – this does not currently appear to be the case in the US under 45Q but may represent a motivation for reporting under ISO 27916 which can be subject to clarification for the first projects considering to apply using ISO 27916.

- The report assesses how ISO 27916 might be applied for CO_2 accounting purposes as a supplement to other regulations by comparing it to four guidelines for accounting CO_2 emissions for CCUS projects: the EU Monitoring and Reporting Guidelines (MRG) (2010)
- the California Air Resources Board – Carbon capture and sequestration protocol under the Low Carbon Fuel Standard (LCFS) (2018)
- the Alberta quantification protocol for CO_2 capture and permanent storage in deep saline aquifers (2015)
- the Canada clean fuel regulations: Quantification method for CO_2 capture and permanent storage (2020).

Under the EU Emission Trading Scheme (ETS), owners of CO_2-emitting industrial facilities need to surrender allowances for each tonne of GHG emitted and can potentially deploy CCS to reduce the number of allowances they need to surrender. The EU MRG focus on the resulting emissions and not the amount of CO_2 stored; operators do not get credits for the CO_2 stored, and these guidelines point to additional emission sources for hydrocarbon recovery operations with CO_2 injection but does not describe the quantification method in detail. ISO 27916 could therefore be used as a supplement to the EU MRG for hydrocarbon operators to inform regulators about the amount of CO_2 stored.

The LCFS, Canadian Clean Fuel Regulations and the Alberta quantification protocol are all set up to allow calculation of GHG emission reductions form CCS projects. The LCFS includes CO_2-EOR but the other two do not. All protocols provide guidance on the calculation of CO_2 reductions, including calculating stored CO_2. ISO 27916 can therefore be used as a supplement to the LCFS CCS protocol to inform regulators on the amount of CO_2 stored associated with CO_2-EOR operations, but because ISO 27916 does not apply to quantification of CO_2 injected into reservoirs with no hydrocarbon production, it is likely not applicable to supplement the Canadian protocols. More detail on these comparisons is included in the report.

Case studies – application in real projects

This section of the report gives insights on how the two ISO standards have been used to guide real projects using DNV experience and information in ISO DTR 27923 Geological storage of carbon dioxide injection operations and infrastructure (published in 2021) and DNV's publication DNV-RP-J203 which is a Recommended Practice to provide a systematic approach to the selection, qualification and management of geological storage sites for CO_2.

1. Determining Site Feasibility For CO_2 Storage

This first case study looked at how DNV-RP-J203 and ISO 27914 were used to determine site feasibility for CO_2 storage for the CarbonNet Project (Australia) and Project Greensand (Denmark).

The CarbonNet Project screening basis defined a total of 20 different screening criteria to be applied to all three sites evaluated. Use of the sire screening process in DNV-RP-J203 showed the portfolio of sites was found to be feasible if at least one of the sites did not have any non-compliant criteria or if there was a combination of sites that combined would not have any non-compliant criteria. A core component of the verification of feasibility according to DNV-RP-J203 is that it emphasises documenting risk and uncertainty assessment at the site screening stage in an initial risk register. The risk register and screening report documenting the basis for the evaluation of risks in the register should provide sufficient information on project risks to be suitable for independent audit and verification.

DNV evaluated site feasibility at Project Greensand by evaluating conformity with the requirements to site screening and site selection in Clauses 5.2 and 5.3 of ISO 27914 and the conformity of the initial risk register and implementation of processes for risk management with ISO 27914. All criteria in Clauses 5.2 and 5.3 are recommendations and are not mandatory requirements. This implies that if a criterion is not considered, the project proponent will or must explain why the relevant recommended criterion is not evaluated (unless this is obvious from the context). To evaluate conformity with ISO 27914, the storage complex and operational limits were described in a screening report with a series of appendices.

A key difference between the evaluation of site feasibility using the two standards DNV-RP-J203 and ISO 27914 lies in the definition of the screening (and site selection) requirements to be evaluated. Certification against DNV-RP-J203 largely follows an approach where a project specific screening basis is defined to reflect the applicable circumstances, and the verification seeks to check if the documentation provided provides the necessary evidence to establish confidence that the requirements in the screening basis have been met. Certification against ISO 27914 (Clause 5.2 and 5.3) on the other hand is dictated by the requirements listed, and the project proponent must provide evidence to support that each requirement is either met or not relevant. There is somewhat less freedom to tailor the ISO 27914 requirements to project specific circumstances. Both ISO 27914 and DNV-RP-J203 require the creation of an initial risk register during the site screening stage, but DNV-RP-J203 has more emphasis on the risk and uncertainty assessment.

2. Requalification Of Wells At CO_2 Storage Sites

This looks at what elements of ISO 27914 can be applied to guide re-qualification of wells at CO_2 storage sites. The Norwegian CO_2 Safety Regulation Section 11 specifically recommends the use of ISO 27914 section 7.6 (as well as DNV-RP-J203 section 7). There are other relevant standards that apply fully to CO_2 storage wells including reuse and requalified wells. ISO 27914 and DNV-RP-J203 deal with the issue of re-qualification of wells differently but complementary. In both, the duty of the operator is to identify suitable well barriers throughout the well lifecycle and specifies what the well integrity risk assessment should include. The key difference between the two on well re-qualification is that ISO 27914 focusses on technical specifications and the performance of each specification in fulfilling its functional demand; and addresses the technical challenges that must be addressed in order to re-qualify wells for re-use. The DNV RP considers the system as a whole and its application to performing the goal of safe and reliable CO_2 storage.

To understand the applicability of both ISO 27914 and ISO 27916 in re-qualifying wells for CO_2 storage, the Kingsnorth CCS project and well integrity evaluation in Europe, were looked at to demonstrate the technical considerations when analysing wells for re-qualification in the absence of the two ISO standards. The Kingsnorth project evaluated wells in the Hewett Field and identified that the existing wells were not suitable for re-use for injection and storage. There is a high level of uncertainty on the status of the wells, and the condition of well barrier elements, due to a perceived scarcity of data and a lengthy operational well life. These factors have contributed to the uncertainty of well integrity.

In the Europe project on well integrity evaluations, around 30 legacy oil and gas wells were investigated. This report presented the findings that highlighted the main challenges including well data quality / data uncertainty, wellbore / geology interactions, and risk-based methods for assessing well integrity and wellbore isolation. Tasks performing well integrity risk assessment, or geological assessment of wells for both hydrocarbon extraction and CO_2 storage, are often split (and this is evident in ISO 27914 and ISO 27916). However, the European work suggested that a synergy of the two may be useful, using historical interactions in the geology and well condition to provide key insights into the difference in the well integrity evaluations.

3. Development Of A Risk-Based M&V Programme

This looks at the extent of the monitoring and verification (M&V) plans developed for Shell's Quest CCS project and Oxy's CO_2-EOR operations at the Denver and Hobbs Field. There are several standards and guidelines covering monitoring plan details, including ISO 27914 and the US EPA Subpart RR rules. The report explains how ISO 27914, RR rules and DNV-RP-J203 guide, the structure of M&V programmes, but does not include ISO 27916 as it provides very limited guidance on the design of an M&V programme.

The Quest CCS project used the CO2QUALSTORE guideline as guidance for the development of the risk assessment approach and the monitoring plan (note that the CO2QUALSTORE guideline was one of several documents that formed inputs into standards that in turn were used as seed documents for the development of ISO 27914). The list of specific tasks in the Quest monitoring programme are more detailed than the guidance provided in ISO 27914, but the list broadly aligns with examples in the note to Clause 9.4.2. Oxy's project in west Texas based its M&V plan on the requirements in the Subpart RR rules and provides clear delineation of the activities for M&V.

ISO 27914 Clause 9 (and ISO DTR 27923) provides guidance on planning and implementation of site-specific, risk-based M&V activities for each project phase. The report recognises that industry guidance is missing a clear indication on post-site closure monitoring and verification activities and consistent follow-up regimes, which are generally covered by local regulation and varies between project locations.

Concept for using standards to assist implementation of CCS projects in regions without tailored regulations

Regulatory Elements Addressed Within ISO 27914 & ISO 27916

GCCSI developed a CCS Legal and Regulatory Indicator (CCS-LRI) in 2018 with a broad range of factors that represent critical elements of the regulation of CCS technology. A high-level mapping exercise was carried out with the CCS-LRI and ISO 27914 and ISO 27916 to provide an indication of the comprehensiveness of the ISO standards and to indicate the areas that a national legislation must cover in addition to the standards.

The ISO standards provide limited specific support for legal and regulatory elements related to:

- the CCS approval process,
- ownership definitions,
- governmental agencies' roles and responsibility,
- ownership regime of the sub-surface,
- transportation of CO_2 (including transboundary movement of CO_2), and
- dispute resolution mechanisms.

The ISO standards support in a general manner the legal and regulatory elements related to:

- definition of the CO_2 stream,
- identification and accounting for CO_2 leakage,
- monitoring, storage and siting, closure,
- reporting and verification,
- public engagement and
- risk assessments.

The report details the CCS-LRI criterion relating to CO_2 storage and marks each criterion with the lowest degree of coverage compared to the most comprehensive coverage with regards to ISO 27914 and ISO 27916.

Regulatory Gap Analysis In Selected Countries

To provide some practical insight into the applicability of regulatory frameworks in selected countries for deployment of CCS technology, DNV looked at the CCS regulatory maturity in Angola, Mozambique, Trinidad and Tobago, Thailand and Indonesia.

Angola: A positive effect of the maturity of the petroleum sector in Angola is a stable petroleum regulatory framework and the existing regulations appear to have most of the appropriate instruments for regulating CO_2 geological storage. Thus, for Angola the most straightforward route to enable CCS appears to be by either amending the existing petroleum law, or by introducing a CCS specific law that builds on the structure and content of the petroleum law. Either approach would require additional articles for site selection and permitting, monitoring and post-injection site care and long-term liability, which could be regulated by requiring compliance with relevant parts of international standards such as ISO 27914.

Mozambique: The technical CCS enabling criteria seems to be promising with good storage potential and reasonable matching of CO_2 sources and storage sites. The capture and transport part of the CCS chain is assessed to be possible to regulate through existing regulations with some modifications, and the storage part by requiring compliance with e.g. ISO 27914. There are however certain showstoppers identified for CCS to develop here, such as a lack of regulatory or commercial incentives, lack of CCS awareness and skilled personnel. It is likely that the introduction of a regulation that would enable CCS would require a significant effort. The existing mining regulation is unlikely to be fit for purpose so the introduction of a new regulation for CO_2 storage, or amendments to the petroleum law, are recommended.

Trinidad and Tobago: The government has looked at CCS as a potential method to reduce the country's GHG emissions and, due to existing legislation that regulates the country's oil and gas sector, this Caribbean state is in a strong regulatory position for CCS to be implemented. It is possible to regulate CCS projects with some modification of the existing regulatory framework or by supplementing with additional CCS legislations. There are, however, some barriers towards regulating CCS in Trinidad and Tobago such as the time it takes for a part of a regulation to complete the governmental and parliamentary process and a potential for CO_2 storage to compete with other subsurface uses.

Thailand: Thailand has no law specifically governing CCS, but there are incentives and a regulatory framework in place that may have the potential to be developed into a regulatory regime for CCS. There are CO_2 sources in the country as well as the potential for using depleted hydrocarbon fields for storage. The initial step for a CCS project, of finding a suitable storage site, has begun. The next steps are to develop a regulatory framework.

Indonesia: Indonesia has a regulatory regime in place for the oil and gas industry as well as environmental protection laws and both public and private sectors are starting to invest in CCS development. There is no specific regulatory framework for CCS projects in place and a regulatory framework is needed to further accommodate the technology.

Application Of ISO 27914 For Permitting CO_2 Storage Projects

The similarity between licensing regimes for oil and gas projects and CO_2 storage projects suggest that the existing petroleum licensing regime, complemented by standards setting specific requirements for CO_2 storage projects, may be combined to form a licensing regime for CO_2 storage projects. The report outlines how ISO 27914 could be used alongside petroleum regulations to form a licensing regime for CO_2 storage. It shows how requirements in ISO 27914 clauses align with the typical requirements for passing key project milestones in a CO_2 storage project, from site selection through to site closure and transfer of responsibility to a post-closure steward, where a mechanism for this is in place. Examples in the report suggest that a conceptual tenure regulation can be developed through the use of a petroleum licensing regime, where the licenses and approvals for O&G exploration, development, production and decommissioning are adapted to also apply to CO_2 storage projects at the corresponding stage of development.

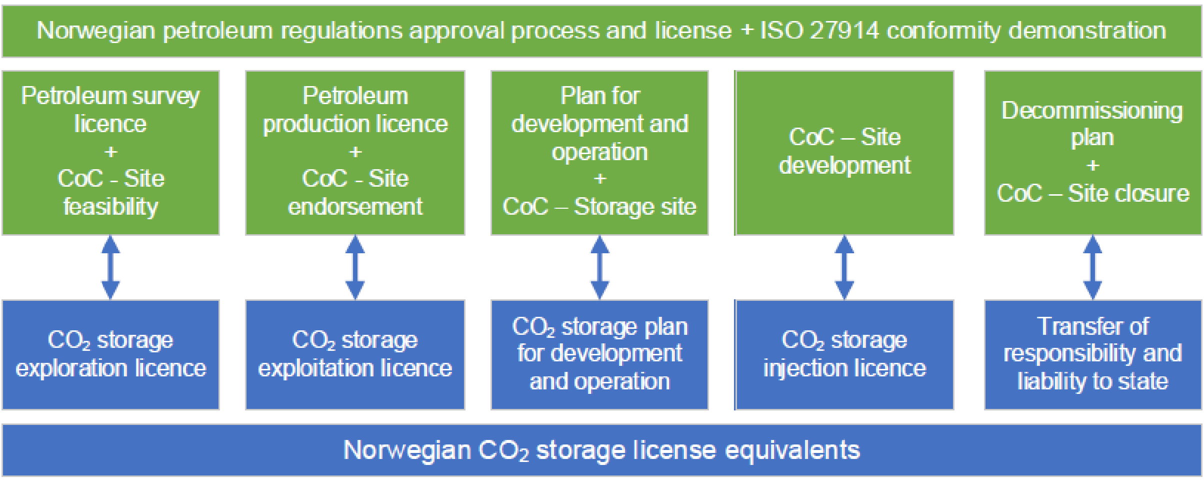


Figure 2. **Conceptual idea for how a tenure regulation could be developed through a petroleum licensing regime and conformity to ISO 27914**. (IEAGHG, 2022)

Figure 2, above, shows an example (specific to Norway) of how process for approvals under petroleum regulations can be combined with a certification of conformity (CoC) with ISO 27914 to meet requirements of CO_2 storage licences throughout a project lifecycle. This example suggests that analogous versions of this conceptual idea could be developed for other petroleum producing jurisdictions and coupling existing licensing regimes with relevant technical requirements in the ISO standard could form a licensing framework for CO_2 storage.

Conclusions

This study summarises, compares and contrasts the ISO 27914 and ISO 27916 standards relating to the geological storage of CO_2 to provide a high-level understanding of the content along with a comparison to international regulatory frameworks. It evaluates the potential use of the two ISO standards as a supplement to existing regulations and mapped the breadth of coverage of the standards relative to various regulatory elements.

ISO 27914 and ISO 27916 are rather complementary with minimal overlap because of the desire of key stakeholders to have a clear separation between the two standards. The two standards are designed to serve different purposes – ISO 27914 aiming to promote commercial, safe, long-term containment of CO_2 in geological systems in a way that minimizes risk to the environment, natural resources, and human health, and ISO 27916 with the objective of promoting the use of geologic storage associated with CO_2-EOR by providing a common process for assuring safe, long-term containment and for quantifying and documenting the amount of CO_2 that is stored in association with CO_2-EOR.

Both ISO 27914 and ISO 27916 can be used together with other industry guidelines to support CCS project development, permitting and approval. Case studies show that ISO 27914 and ISO 27916 can be used to guide processes for evaluating technical challenges on three key topics: determining site feasibility, re-qualification of wells and the development of a risk-based M&V programme.

There are many similarities between oil and gas activities (related to exploration, development, production and decommissioning of oil and gas fields) and activities required for exploration, development, operation and closure of CO_2 storage sites. Regulations for governing CO_2 storage activities are often similar to petroleum regulations in the particular region. The similarities between petroleum regulations and CO_2 storage projects suggest that the existing petroleum licensing regime, complemented by standards setting specific requirements for CO_2 storage projects that are not adequately reflected in the petroleum regulations, may be combined to contribute to the development of a licensing regime for CO_2 storage projects. Areas within regulations for CO_2 storage and CO_2-EOR that are not covered by ISO 27914 and ISO 27916 include the management of long-term liability and regulatory approval processes.

Expert Review

The report was reviewed by eight external experts who provided varying levels of comments on the content of the report. The general consensus was that the document was well written and a useful piece of work which met the objectives and scope of the project. Received particularly well were the various tables contrasting the standards and other guidance documents.

There were some comments noting that the contractors described their own processes in too much detail, which was addressed in the final iteration by significantly editing where appropriate. It was acknowledged that the DNV documents have been used to inform regulations, so it is useful to include discussion of their use in places. The contractors agreed that promotional language had to be toned down, however their ability to draw from relevant experience in developing certification documents is still valuable input to this study.

There were a few suggestions on how to frame the role of standards in regulatory frameworks and that it was important to identify gaps in the standards and not just suggest that they should be used with supplementation from other best practice documents. The contractors added text to provide clarity and further explanation where gaps were recognised by the reviewers, but did not edit to include any more than the high-level guidance as specified in the study scope.

It was suggested that ISO standards applicable to capture and transport should be referenced to in the report, but it was recognised that this was outside of the scope of this particular study but may be a worthwhile avenue for future work.

It was recognised that ISO standards could contain some inconsistencies and / or errors, but that the standards are an evolving entity and subject to refinement and continuous updating where deemed necessary by an independent panel (ISO operate a 5-year review cycle on all published standards). Experts have recognised that ISO standard 27914:2017 may be difficult to actually implement for real projects due to the large number of non-technical requirements, and perhaps this standard could be seen as more of a best practice guide. However, it was not within the scope of this study to draw out inconsistencies, only to summarise and contrast the two standards, providing a high-level understanding of the contents and to assess their applicability to actual CO_2 storage projects, but it is important to recognise that ISO 27914:2017 is likely better used to complement a regulatory regime, rather than as a standalone guide.

Recommendations

This study provides a high-level but comprehensive insight into the ISO standards that are related to the geological storage of CO_2: ISO 27914:2017 ('Carbon dioxide capture, transportation and geological storage — Geological storage') and ISO 27916:2019 ('Carbon dioxide capture, transportation and geological storage — Carbon dioxide storage using enhanced oil recovery (CO_2-EOR)').

IEAGHG have concluded with key recommendations following the completion of this study:

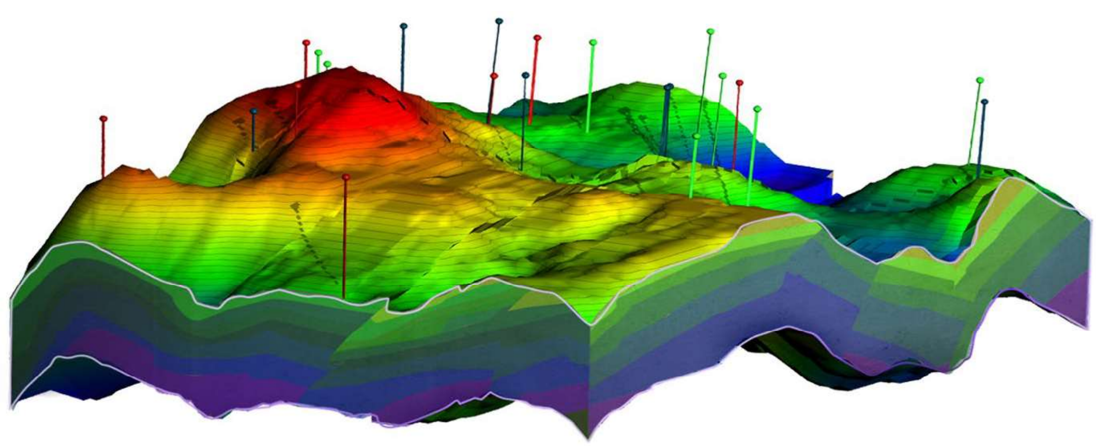
- The two ISO Standards, ISO 27914 and ISO 27916, are valuable tools and could be recommended for use by CO_2 storage project proponents and regulators to assist as suggested best practice guidelines for the development of CO_2 storage projects.
- This work only looks into the relevance of ISO standards to the geological storage of CO_2; it may be beneficial to carry out additional studies that look at the applicability of ISO standards to other parts of the CCUS chain, such as capture and transport.
- Further work could be done on assessing how any gaps in the standards (where limited specific support for various legal and regulatory elements is limited) could be addressed.
- ISO standards are developed, written and reviewed by a group of experts, and then subject to periodical review and where appropriate, editing of the content. They are updated continuously, as is in the nature of standards development, so it must be remembered that this particular report is providing an insight into how the standards are applicable at the time of study publication. ISO 27914:2017 in particular is better used to complement regulatory regimes, as a set of best practices. More work needs to be done on the ability to actually implement the standards. Further research on how operators would certify a project under either standard is also recommended.

APPLYING ISO STANDARDS TO GEOLOGIC STORAGE AND EOR PROJECTS

Application of ISO 27914 and ISO 27916 to support implementation of CCUS projects

IEA Environmental Projects Ltd

Report No.: 2021-0862, Rev. A
Document No.: 1128189
Date: 2021-12-13



Project name:	Applying ISO Standards to Geologic Storage and EOR Projects	DNV AS Oil & Gas Well & Asset Risk Veritasveien 1
Report title:	Application of ISO 27914 and ISO 27916 to support implementation of CCUS projects	
Customer:	IEA Environmental Projects Ltd, Cheltenham Office Park Hatherley Lane, GL51 6SH Cheltenham United Kingdom	1363 Høvik Norway
Customer contact:	Samantha Neades and Tim Dixon	Tel: +47 67 57 99 00
Date of issue:	2021-12-13	945 748 931
Project No.:	10291972	
Organisation unit:	Well & Asset Risk	
Report No.:	2021-0862, Rev. A	
Document No.:	1128189	

Applicable contract(s) governing the provision of this Report: Contract Letter IEAGHG Ts&Cs_2021 DNV

Objective:

The purpose of this study was to summarise, compare, and contrast the published ISO standards relating to the geological storage of carbon dioxide (ISO 27916 and ISO 27914) with current regulatory frameworks and provide a high-level understanding of the content of the standards. The study focused on the aspects related to geological storage and does not include capture and transport of CO_2.

Prepared by:

Aarnes, Jørg Digitally signed by Aarnes, Jørg Date: 2021.12.10 14:29:02 +01'00'

Jørg Aarnes
Global Lead – Hydrogen and CCS

2021.12.13 08:58:00 +01'00'

Embla Larsdotter Holten
Principal Engineer

Digitally signed by Buchmiller, David Date: 2021.12.13 10:01:15 +01'00'

David Buchmiller
Principal Engineer

Verified by:

Magnus Killingland
Regional Segment Lead – Hydrogen and CCS Northern Europe

Approved by:

Afzal Hussain
Head of Section

DNV Distribution:

☐ OPEN. Unrestricted distribution, internal and external.

☐ INTERNAL use only. Internal DNV document.

☒ CONFIDENTIAL. Distribution within DNV according to applicable contract.*

☐ SECRET. Authorized access only.

*Specify distribution:

Keywords:
CCS, CCUS, Carbon Capture and Storage, CO2 Storage, CO2 Sequestration, CO2 Enhanced Oil Recovery, CO2 EOR, Well integrity

Rev. No.	Date	Reason for Issue	Prepared by	Verified by	Approved by
0	2021-12-13	First issue	JORGA/ EMBHOL / DAVBU	MAGKIL	AHUS

Table of contents

1 EXECUTIVE SUMMARY

DNV has compiled a review and assessment of industry knowledge, standards, guidelines and project references related to IEAGHG's technical specification request "Applying ISO Standards to Geologic Storage and EOR Projects" IEA/CON/21/276. Background for this report is that the International Standards Organization (ISO) has published the standards ISO 27914:2017 *'Carbon dioxide capture, transportation and geological storage — Geological storage'* (ISO, 2017a) and ISO 27916:2019 *'Carbon dioxide capture, transportation and geological storage — Carbon dioxide storage using enhanced oil recovery* (CO_2-EOR)' (ISO, 2019). Henceforth these two standards will be referred to as ISO 27914 and ISO 27916. An analysis and in-depth comparison of these two ISO standards, other industry references and a deeper dive into relevant case studies are covered in this report. The purpose of this study is to summarise, compare, and contrast the published ISO standards relating to the geological storage of carbon dioxide (ISO 27916 and ISO 27914) with current regulatory frameworks and provide a high-level understanding of the content of the standards.

Firstly, a synthesis of ISO 27914 and ISO 27916 is provided, showing similarities, differences and relative gaps in the standards. The synthesis goes further to compare the potential use of the two ISO standards in guiding the permitting process based on existing regulations for CO_2 storage and for EOR in Europe, North America and Australia.

Secondly, the applicability of ISO 27914 and ISO 27916 as a supplement to existing regulations was analysed to show potential application cases of storage site permitting, application approval and evaluation of closure requirements.

Thirdly, in three case studies DNV analysed the extent that ISO 27914 and ISO27916 have been or can be applied to guide processes for site feasibility evaluations, well re-qualification for CO_2 storage, and developing a monitoring and verification program.

Fourthly, a conceptual evaluation was performed of the potential for using ISO 27914 and ISO 27916 to assist implementation of CCS projects in countries lacking mature CCS regulations.

Key takeaways from the study include:

1. ISO 27914 and ISO 27916 are to a high degree complementary, with minimal overlap. A key reason for this was the desire by key stakeholders to achieve a clear separation between the two standards, so that ISO 27914 would apply only to CO_2 storage projects and ISO 27916 would apply only to CO_2 EOR projects.
2. The standards are designed to serve different purposes. The objective of ISO 27914 is to promote commercial, safe, long-term containment of CO_2 in geological systems in a way that minimizes risk to the environment, natural resources, and human health. The objective of ISO 27916 is to promote the use of geologic storage associated with CO_2-EOR by providing a common process for assuring safe, long-term containment and for quantifying and documenting the amount of CO_2 that is stored in association with CO_2 EOR.
3. ISO 27914 and ISO 27916 together with other industry guidelines can support CCS project development and permitting and approval.
4. Case studies show that ISO 27914 and ISO 27916 can be used to guide processes for evaluating technical challenges on three key topics in alignment with industry best practice knowledge. These topics are:
   - Determining site feasibility for CO_2 storage
   - Re-qualification of wells at CO_2 storage sites
   - Development of risk-based monitoring and verification programs
5. There are several similarities between activities related to development, production and decommissioning of oil and gas (O&G) fields, and activities required for exploration, development, operation and closure of CO_2 storage sites. Regulations that have been introduced for governing CO_2 storage activities are therefore often mimicking the petroleum regulations in the region to a large extent. The similarity between licensing regimes for O&G developments and CO_2 storage projects also suggest that the existing petroleum licensing regime,

complemented by standards setting specific requirements for CO_2 storage projects that are not adequately reflected in the petroleum regulations, may be combined to contribute to the development of a licensing regime for CO_2 storage projects. Areas within regulations for CO_2 storage and CO_2 EOR that are not covered by ISO 27914 and ISO 27916 include the management of long-term liability and regulatory approval processes.

2 SYNTHESIS AND COMPARISON WITH REGULATIONS

This section provides a brief synthesis of ISO 27914 and ISO 27916, and explains where they overlap and where they do not. We also assess where and how the standards might be used or applied to support regulatory purposes. This is done by comparing and contrasting the standards with requirements in relevant existing regulations.

It should be noted that ISO 27914 and ISO 27916 have not been designed to be a replacement for regulations. The comparison provided in Sections 2.4 and 2.5 should therefore be viewed as an analysis of how the standards aligns with and complements existing regulations.

2.1 Synthesis of ISO 27914

ISO 27914 is first and foremost intended to establish requirements and recommendations for the geological storage of CO_2 streams. The core purpose of the document is to promote commercial, safe, long-term containment of carbon dioxide in a way that minimizes risk to the environment, natural resources, and human health. ISO 27914 applies to projects with injection of CO_2 into porous geologic units for the *sole* purpose of storage, both onshore and offshore. It is not intended to serve as a guide for projects that:

- inject CO_2 for the purpose of enhancing production of hydrocarbons,
- dispose other acid gases (unless part of the CO_2 stream),
- dispose waste and other matter added for purpose of disposal,
- inject CO_2 for storage in coal, basalt, shale and salt caverns, or
- store CO_2 underground using any form of buried container.

Application of ISO 27914 is voluntary, except when specifically required as part of applicable regulatory requirements. It is a supplement to regulations, and *does not apply to, modify, interpret, or supersede any national or international regulations, treaties, protocols or instruments otherwise applicable to the activities addressed* in the standard.

The structure of the document broadly follows the life-cycle of a CO_2 storage project:

- Clause 5 describes requirements and recommendations to pre-injection site screening, site selection, and site characterization and modelling activities.
- Clause 7 presents requirements to the well infrastructure development and maintenance and decommissioning. This includes specifications for materials, design, construction and completions, corrosion control, evaluation, recompletion, workover and abandonment.
- Clause 8 presents requirements to injection site operations. This entails requirements to operations design, plans and procedures for operations (including routine and non-routine shutdown of injection), well interventions, and data acquisition monitoring and testing.
- Clause 10 describes criteria for site closure and the plan and qualification process to demonstrate adherence to these criteria.

The standard does not suggest any requirements or recommendations following site closure, which occurs when the project operator has demonstrated compliance with criteria for site closure. Also, while the standard acknowledges that permitting and approval by regulatory authorities will be required at different points in the project life cycle, it does not provide specific recommendations for implementing the permitting processes.

In addition, the standard has three clauses that are relevant for all stages of the project life cycle.

- Clause 4 provides recommendations to management systems. This includes requirements to specification of roles and responsibilities, stakeholder engagement, delineation of project boundaries, commitment to principles, planning and decision-making, allocation and competence of resources, communication and documentation.
- Clause 6 describes requirements and recommendations for risk management. This clause builds on requirements to the risk management process in ISO 31000, while acknowledging that risk management for CO_2 storage sites needs to be based on site specific knowledge and context. I.e., it recognizes that site selection and management are unique for each project and that intrinsic technical risk and uncertainty will be dealt with on a site-specific basis. This clause also includes guidance on risk management communication and consultation.
- Clause 9 provides requirements and recommendations to monitoring and verification (M&V). The clause specifies required objectives of M&V, as well as requirements to the M&V plan, and acknowledges that there are different monitoring needs for different periods in the life cycle. This clause (and Clause 8) also specifies requirements to measurements necessary for accounting of greenhouse gas emissions, but the standard does not describe procedures or calculations for quantification of CO_2 stored or CO_2 emissions avoided. This is currently a key difference compared with ISO 27916. It can be noted, however, that there is currently a New Work Item Proposal under ISO TC 265 for revision of ISO 27914 where the primary purpose of the revision is to include guidance on quantification and verification.

During the development of ISO 27914 it was acknowledged that CCS is still a nascent industry. It is therefore important to enable continuous improvement and application of best available technology, as more experience and learnings are obtained. To this end, some principles were established to guide the level of detail to be included and avoid that the standard becomes too prescriptive. The main principle was that the standard should seek to describe the objectives (why activities need to be performed, and the performance expectations for these activities), and requirements to the process and plans to meet these objectives. The standard should broadly refrain from dictating which specific activities or technologies need to be executed or deployed, or how the objectives shall be met beyond the process requirements. The following example was provided to the working group developing the standard:

- Build a safe comfortable house (objective)
    - Suitable for local environment (sub-objective)
        - Building plan (the “what”)
            - Adjustable thermostat (too much detail – leave the options open)

Furthermore, it was acknowledged that numerous standards already exist that are applicable to elements of geological storage projects. This applies particularly to the well infrastructure. The intent was that ISO 27914 should, to the extent possible, be a stand-alone document, while limiting overlap with other standards. The approach was to specify additional considerations or needs that are unique to safely managing CO_2 injection and storage, and reference other related recommended practice manuals or standards when relevant.

2.2 Synthesis of ISO 27916

ISO 27916 principally applies to the process of quantifying and documenting the amount of CO_2 that is stored in association with CO_2-EOR, and provides a means for highlighting the part of this CO_2 that stems from anthropogenic greenhouse gas emissions sources. This quantity enters into equations for calculating greenhouse gas emissions reductions associated with CO_2 EOR projects. It is therefore anticipated that the standard will support development of rules for accounting of greenhouse gas emissions for CO_2 EOR projects, and that the quantified amount of CO_2 stored may be used as input for calculations conducted in accordance with a number of other standards, protocols or programs for the quantification or reporting of greenhouse gas emissions. This will be discussed in relation to regulatory protocols for calculating greenhouse gas emissions for the full CCUS chain in Section 3.

ISO 27916 also provides requirements for demonstrating that an EOR site is adequate to provide safe, long-term containment of CO_2, and for demonstrating that the CO_2 flood is operated in a way to assure containment of the CO_2 in the EOR complex. This includes the requirements for

- documentation (Clause 4) and record keeping (Clause 9),
- description, qualification and construction of the EOR complex (Clause 5),
- monitoring and provision of *containment assurance* (Clause 6),
- well construction and well intervention (Clause 7), and
- project termination (Clause 10).

It should be noted, however, that the clauses above are less prescriptive than related clauses in ISO 27914, and generally provide only high-level guidance. For instance, demonstration of the suitability of the EOR complex is reflected in two broad requirements to demonstrate the following:

- the geological characterization and engineering description shall provide evidence of the integrity of the reservoirs and traps that supports a conclusion that the EOR complex is suitable for safe, long-term containment, and
- each well penetrating the EOR complex […] shall be constructed and/or plugged & abandoned in such a manner as to provide safe, long-term containment of CO_2.

Only slightly more detail is provided in Clause 7:

- Description of new wells/well modifications shall provide evidence that they are designed, constructed, and tested to provide safe, long-term containment of CO_2. Well materials, including metals, cements, and elastomers, shall be selected based on their ability to withstand the expected operational environment including the thermomechanical stress of operation and the geochemistry (including CO_2 where present) of the subsurface.

The core part of ISO 27916 is Clause 8 – Quantification. ISO 27916 *"does not apply to quantification of CO_2 injected into reservoirs where no hydrocarbon production is anticipated or occurring"*. The application of the standard for CO_2 storage projects is therefore explicitly excluded. However, some of the equations in this Clause 8 may in principle also be used to quantify amount of CO_2 stored for projects injecting CO_2 for the sole purpose of storage (e.g. CO_2 injected, CO_2 leakage and fraction of anthropogenic CO_2).

In addition, the application of ISO 27916 for the following purposes is excluded or not intended:

- Calculation of lifecycle emissions for the full CCUS chain. This also excludes any calculation of emissions from capture or transportation of CO_2 and combustion or use of produced hydrocarbons.
- Storage of CO_2 above ground.

- Buffer and seasonal storage of CO_2 below ground.
- Calculation of other greenhouse gases emissions.
- Selection, characterization or permitting of sites for CO_2 EOR projects.

In essence, the amount of CO_2 stored is the amount injected minus the amount CO_2 lost. The CO_2 lost is a combination of CO_2 vented (intended releases), fugitive emissions/leakage (unintended releases), or CO_2 transferred from the EOR project. This is covered in existing protocols, such as the *Greenhouse Gas Accounting Framework for Carbon Capture and Storage Projects* by the Center for Climate and Energy Solutions (C2ES, 2012). One novel element of ISO 27916 is how it deals with anthropogenic versus non-anthropogenic CO_2. It provides guidance on estimating fraction of anthropogenic CO_2 in the quantified stored CO_2, and considers the possibility of including native CO_2. To provide comment on this, we first state the definitions:

- **anthropogenic carbon dioxide**: carbon dioxide that is initially produced as a by-product of a combustion, chemical, or separation process (including separation of hydrocarbon-bearing fluids or gases) where it would otherwise be emitted to the atmosphere (excluding the recycling of non-anthropogenic CO_2, i.e. CO_2 specifically extracted from a subsurface geological formation for the purpose of being used for CO_2 EOR, and not as a bi-product of hydrocarbon exploration or production).
- **native CO_2**: CO_2 present and indigenous within the project reservoir prior to hydrocarbon production or any CO_2 injection.

Normally, market mechanisms that offer an incentive for storing CO_2 will only provide credits for storage of anthropogenic CO_2, but operators may want to keep track of the full amount of CO_2 stored. The concept of including native CO_2 in emission calculations, and possibly getting credits for this is, however, new. The rationale for including native CO_2 is put forward in Note 2 of Clause 8.2:

- *Native CO_2 present in the project reservoir prior to starting a CO_2 EOR project is typically separated from produced hydrocarbons during production and emitted to the atmosphere. When hydrocarbon production progresses to CO_2 EOR and if recycling facilities are installed, the native CO_2 is no longer emitted, but is captured and retained for direct use by the CO_2 EOR project and is combined with the CO_2 received from other sources.*

Inclusion of native CO_2 that is re-injected in the quantification of CO_2 stored was one of the most debated issues in the preparation of ISO 27916. In the development of the standard, it was recognized that regulatory authorities may have different perspectives on whether the inclusion of native CO_2 should be allowed in the emissions accounting. The standard therefore states that produced, captured and reinjected native CO_2 *may* be included in the quantification of stored CO_2 if this is approved by the authority.

Detailed guidance, with examples, on how to estimate the anthropogenic portion of CO_2 stored, and the amount of native CO_2 stored, is provided in Appendix B of ISO 27916.

2.3 Comparison of ISO 27914 and ISO 27916

ISO 27914 and ISO 27916 are to a large degree complementary, with minimal overlap. First, ISO 27914 explicitly excludes its application to CO_2 EOR projects, and ISO 27916 explicitly excludes its application to projects injecting CO_2 for the sole purpose of storage. A key reason for these exclusions is that during development of ISO 27914 and ISO 27916 it was desired by key stakeholders to have a clear separation between the two standards, so that ISO 27914 would apply ***only*** to CO_2 storage projects and ISO 27916 would apply ***only*** to CO_2 EOR projects.

For clarity, ISO 27914 is applicable to storage of CO_2 in hydrocarbon fields that oil and gas production is not occurring or planned, provided the purpose of the storage is safe, long-term containment. Interim storage of CO_2 in geological systems, e.g. CO_2 that is intended to be recovered at a later point in time, and storage of CO_2 in hydrocarbon fields planned for future production, but without ongoing hydrocarbon recovery, is not covered in neither standard.

The two standards are designed to (principally) serve quite different purposes. The objective of ISO 27914 is to promote commercial, safe, long-term containment of carbon dioxide in a way that minimizes risk to the environment, natural resources, and human health. The objective of ISO 27916 is (principally) to promote the use of CO_2 EOR for CO_2 storage by providing a common process for recognizing, quantifying and documenting the amount of CO_2 that is stored in association with CO_2 EOR.

There are, however, elements of ISO 27914 that could provide guidance for CO_2 EOR projects. This would apply, for instance, to much of the content in Clause 7 – Well infrastructure, Clause 8 – CO_2 storage site injection operations, and Clause 9 – Monitoring and verification, as well as Clause 4 – Management systems. It should be noted, however, that ISO 27914 is more prescriptive or has more detailed information, and therefore also includes requirements that would be additional to what is required by ISO 27916 alone. For instance, ISO 27916 has no specific requirements for a monitoring plan, whereas ISO 27914 has a sub-clause detailing requirements for the M&V plan. Conversely, parts of ISO 27916 would be functionally applicable to CO_2 storage projects, such as elements of Clause 8 – Quantification.

The applicability of the standards to provide guidance on specific sub-topics of relevance for both CO_2 storage and CO_2 EOR projects is summarised below in Table 2-1. To assist in easy screening, we have applied colours to indicate applicability. Green signals applicability, yellow signals partial applicability and red signals not addressed/included.

Table 2-1: High level comparison of ISO 27914 and ISO 27916. Green signals applicability, yellow signals partly applicability and red signals not addressed.

Topic	ISO 27914	ISO 27916
Management systems	Clause 4 (+ e.g. 6.5 and 8.3)	Operations management plan, and requirements for documentation and record-keeping (Clause 4 and 9)
Risk management	Clause 6	Mentioned, but very limited guidance on how to manage risks. Mainly Clause 6.
Well infrastructure	Clause 7	Very high level, limited guidance
Operations	Clause 8	Some high-level guidance in Clause 6.1
Monitoring	Clause 9	Some high-level guidance in Clause 6.2
Site closure/Project termination	Clause 10	Clause 10
Quantification of GHG emissions		Clause 8, quantification of CO_2 stored
Permitting		
Stakeholder consultation/communication	High level guidance in Clause 4.1.3 and 4.6 + guidance on risk communication and consultation in Clause 6.10	
Environmental (impact) assessment		
CO_2 composition	Limited guidance, e.g. Clause 5.4.4	
Post closure/termination		

2.4 Comparison of ISO 27914 with existing regulation for CO_2 storage

While we recall that *ISO 27914 does not apply to, modify, interpret, or supersede any national or international regulations, treaties, protocols or instruments otherwise applicable to the activities addressed*, the document provides additional guidance on matters dealt with under the regulations. Conformity with this guidance may therefore in some cases be considered by regulatory authorities as part of approval processes. In general, the regulations only stipulate high-level requirements, whereas ISO 27914 provides guidance on processes, materials, techniques and plans that can be put in place to enable the regulatory requirements to be met with confidence.

It can be noted that there are a few examples of regulations where specific reference is made to ISO 27914, so that adherence to the standard is recommended or required. One example is the (proposed) delegated act of the EU Taxonomy[1]. The technical screening criteria for *underground permanent geological storage of* CO_2 require that for the exploration and operation of storage sites within the EU, the activity complies with EU CCS Directive. For the exploration and operation of storage sites in third countries, the activity complies with ISO 27914 (European Commission, 2021).

Another example is the guidelines regarding regulations for the safety and working environment for transport and injection of CO_2 into submarine geological formations on the Norwegian continental shelf (Petroleum Safety Authority Norway, 2020b). In this guideline it is specified that DNV-RP-J203 (DNV, 2017b) Section 7 **and** ISO 27914 Chapter 7.6 *should* be used to assess the well barriers[2] to existing wells when storing CO_2. This applies to wells that are in use and temporarily or permanently abandoned wells.

The authors of this report are not aware of any other mentions of ISO 27914 in existing regulations or regulatory guidelines that provide a mandate or recommendation to use the standard.

Table 2-2 provides an overview of relevant parts of selected regulations (U.S. Class VI rules (U.S. EPA, 2010), EU CCS Directive (European Commission, 2009), and Australian Commonwealth regulations (Australian Government)) for each of the key chapters in ISO 27914.

[1] The EU Taxonomy establishes technical screening criteria for determining the conditions under which an economic activity qualifies as contributing substantially to climate change mitigation or climate change adaptation and for determining whether that economic activity causes no significant harm to any of the other environmental objectives.

[2] Well barrier is defined in NNORSOK D-010 as "envelope of one or several dependent barrier elements preventing fluids or gases from flowing unintentionally from the formation, into another formation or to surface" (NORSOK)

Table 2-2: Comparison of ISO 27914 with regulations for CO_2 storage in EU, the US and Australia.

Clause in ISO 27914	EU CCS Directive[3]	US Class VI rules	Australian Offshore GHG Storage Act + regulations
1. Scope/Purpose Establish requirements and recommendations for the geological storage of CO_2 streams, […] to promote commercial, safe, long-term containment of CO_2 in a way that minimizes risk to the environment, natural resources, and human health.	**Alignment** Establish legal framework for environmentally safe geological storage of CO_2 to prevent and, where this is not possible, eliminate as far as possible negative effects and any risk to the environment and human health.	**Alignment** Protect Underground Sources of Drinking Water (USDWs) in accordance with Safe Drinking Water Act (SDWA). The Class VI rules sets forth the technical criteria and standards that must be met in permits and authorizations for geological storage of CO_2.	**Partly aligned** The object of the Commonwealth Offshore Petroleum and Greenhouse Gas Storage Act 2006 is to provide an effective regulatory framework for both: (a) petroleum exploration and recovery; and (b) the injection and storage of greenhouse gas substances; in offshore areas.
4. Management systems … to allow and promote improvement in the management of the CO_2 storage projects, while ensuring that QA/QC, regulatory compliance, process improvements, and efficiency improvements are integrated into regular management processes and decision-making, and providing transparency for stakeholders, regulatory authorities and the public.	**Not explicitly covered, but some overlap** Requirements to contents of permits, reporting, communication of change, and record keeping.	**Not explicitly covered, but some overlap** Requirements to reporting, recordkeeping, and management of area of review (AoR), including requirement to *prepare, maintain, and comply with a plan to delineate the AoR for a proposed geologic sequestration project, periodically reevaluate the delineation, and perform corrective action.*	**High level guidance** A key element of the regulation is a requirement for a Site Plan. In this plan there is, for instance, requirements to *set out an integrated operations management plan, showing clear chains of command where appropriate,* and provide information about project planning and management, including access to resources joint venture arrangements.
5. Site screening, selection and characterization … requirements and recommendations for screening, selection and characterization of sites to determine if they qualify as sites for safe, long-term containment of CO_2 for the planned project.	**Alignment, but higher level** The suitability of a geological formation for use as a storage site shall be determined through a characterisation and assessment of the potential storage complex and surrounding area pursuant to the criteria specified in Annex I of the Directive.	**Alignment, but higher level** Relevant requirements are contained in the following parts of the Class VI rules (under 40 CFR Part 146): - 146.82 (permit information), (a)-(h) - 146.83 (minimum criteria for siting) - 146.84 (Area of review and corrective action), (c)	**Alignment, but higher level** An application for "Declaration of Storage Formation", requires a description and detailed analysis of *the geological features and effective sealing feature, attribute or mechanism that enables the permanent storage*. Schedule 1, Part I of the regulation specifies information to be provided.
6. Risk management … requirements to risk management throughout all stages of the project life cycle.	**Alignment** 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. Guidance on risk assessment in Section 3.3 of Annex I. Guidance on establishing and updating a (risk-based) monitoring plan in Annex II.	**Alignment, but higher level** No specific risk assessment and risk management plan requirement, but addressed indirectly in e.g.: - 146.84 (Area of review and corrective action), - 146.93 (Post-injection site care and site closure) - 146.94(a) (Emergency and remedial response)	**Limited guidance** The regulation provides some guidance related to determination that there is no significant risk of significant adverse impact (SROSAI) on other operations under the Act. This also entails impacts to petroleum operations occurring or planned near the storage site. Further, the site plan must demonstrate that risks have been, or will be, eliminated or reduced to as low as practicable, and that new risks or increases in the level of existing risks will be identified as they arise.

3 The CCS Directive broadly reflects the regulations introduced by European member states and Norway when transposing the directive into national law, although notable deviations exist between the CCS Directive and its national implementation exist, e.g. in Germany.

Clause in ISO 27914	EU CCS Directive[3]	US Class VI rules	Australian Offshore GHG Storage Act + regulations
7. Well infrastructure … requirements to materials, design and construction of wells related to geological storage of CO_2, from point of delivery of CO_2 to the storage facility through to the wellhead(s) and well(s).	**No guidance**	**Alignment for injection wells, less guidance for other wells** Specific requirements for injection wells in 40 CFR Parts 146.86 (Injection well construction requirements) and 146.89 (Mechanical integrity). All other wells that may penetrate the confining zone must be identified and evaluated to ensure the wells will prevent the movement of fluid into or between USDWs, including use of materials compatible with the carbon dioxide stream, where appropriate, or be corrected.	**No guidance**
8. CO_2 storage site injection operations … requirements to CO_2 injection operations (for geological storage) that take place within the storage site. Note: ISO 27914 states that modelling shall determine the maximum CO_2 injection pressure that will ensure no loss of integrity of the **primary seal.** It also defines injectivity as “rate and pressure at which fluids can be pumped into the storage unit without fracturing the **storage unit**.	**Limited guidance (only CO_2 composition)** Definition of CO_2 stream in ISO 27914 is aligned with requirements to CO_2 composition in Directive.	**General alignment** Injection well operating requirements is specified 40 CFR Part 146.88. The requirements are generally aligned with requirements in ISO 27914, but much less comprehensive guidance. One notable difference is that the Class VI rule specifies that the injection pressure shall not exceed 90 percent of the fracture pressure of the **injection zone(s)**, and also not initiate fractures in the **confining zone(s)**.	**Limited guidance** The site plan must describe any current or proposed injection and storage operations of the applicant. The information must include a description of the facilities, proposed rates of injection, injection pressures, number and location of injection wells, and the source, composition and other relevant physical and chemical properties of each greenhouse gas substance proposed for storage.
9. Monitoring and verification (M&V) … requirements to development and execution of a site-specific M&V plan (Clause 9 and 8.5).	**Aligned** Requirements are specified in Article 13, and specifications for the M&V plan is provided in Annex II part 1.1. Both documents focus on objectives of monitoring and information to be provided, and process for selecting suitable technologies.	**Aligned** Requirements to testing and monitoring is specified in CFR 40 Part 146.90. The emphasis is on objectives of the monitoring plan. A small deviation is that it states that monitoring to track the extent of the CO_2 plume and elevated pressure **must** (as default) include both direct and indirect methods.	**Aligned** The site plan shall provide a monitoring plan that will identify any new or increased risks in a timely manner, and appropriate arrangements for compliance with this plan. Schedule 2 parts 7-10 provides specific guidance for development of this plan.
10. Site closure … criteria for site closure and requirements of a process to demonstrate compliance with these criteria. Conformity with the site closure criteria should *provide a high degree of confidence that injected CO_2 will be retained within the storage complex and that risk associated with the project is de minimis.* ISO 27914 does not include any time-based criteria (duration of post-injection site care and monitoring) for closure.	**Partly aligned** Site closure in ISO 27914 corresponds to Transfer of responsibility (Article 18) in Directive. The criteria listed in ISO 27914 Clause 10.2 are broadly aligned with criteria 18.1 (a) and (d) and 18.2 (a) and (b). The Directive also has three additional conditions for transfer of responsibility: 1. A minimum period has elapsed since end of injection (20 years). 2. Financial obligations have been met. 3. Site is site is evolving towards a situation of long-term stability.	**Partly aligned** The key criterion for site closure is that the operator provides *substantial evidence that the geologic sequestration project will no longer pose a risk of endangerment to USDWs at the end of the alternative post-injection site care timeframe*. The default time frame is 50 years. In addition, the rules provide specific requirements to the plugging of injection wells. The key deviation from ISO 27914 requirements is the specification of the default duration of post-injection site care prior to closure.	**Partly aligned** The regulation specifies requirements to information to be provided to acquire a closing certificate. This includes work required to *remediate any abandoned wells or other features that could pose a risk of leakage of the greenhouse gas substance*, and monitoring to be undertaken after injection has ceased. The licensee must also provide a plan for decommissioning structures and equipment. The Commonwealth can assume the long-term liability following the closure assurance period, which by default is 15 years.

2.5 Comparison of ISO 27916 with existing regulation for CO_2 EOR

2.5.1 Class II rules under US EPA UIC program

In the US, CO_2 EOR operations are regulated by the US Environmental Protection Agency (EPA) UIC (Underground Injection Control) program[4]. Operators need to acquire a Class II well permit (U.S. EPA). The key requirements for Class II permits are specified in CFR 40 Parts 146.22 (well construction), 146.23 (operating, monitoring and reporting) and 146.24 (information). A comparison of these requirements with those in ISO 27916 is provided in Table 2-3.

Table 2-3: Comparison of ISO 27916 and the US EPA UIC rule for Class II wells.

Clause in ISO 27916	US Class II rules
Documentation (Clause 4) and recordkeeping (Clause 9) High level guidance on: - initial documentation (description of EOR complex, initial containment assurance, monitoring program, and method for quantification of CO_2 stored); and - periodic documentation (CO_2 sources, quantity of CO_2 stored, and estimation of missing data).	**Some guidance** Annual reporting of the results of required monitoring. This includes monthly records of injected fluids, and any major changes in characteristics or sources of injected fluid.
EOR complex characterization and containment assurance Clause 5 specifies that the operator shall prepare an EOR management plan and establish that the EOR complex and engineered systems (including wells) are adequate to provide safe, long-term containment of CO_2. Clause 6.1 describes requirements to the EOR management plan and containment assurance plan, as well as conditions that may require the EOR management plan to be revised. The containment assurance plan shall identify and assess potential geologic, engineered, and engineering-affected leakage pathways that might lead to loss of CO_2 from the EOR complex.	**Alignment, but much more detailed (prescriptive) guidance** The rule provides detailed guidance on information to be considered when granting permits for Class II wells. This includes a map showing the injection well or project area for which a permit is sought and the Area of Review (AoR)[5], a tabulation of data reasonably available on all wells within the AoR which penetrate the proposed injection zone or, penetrate formations affected by the increase in pressure, proposed operating data, and appropriate geological data on the injection zone and confining zone including lithologic description, geological name, thickness and depth, proposed contingency plans, and plans for meeting the monitoring requirements.
Monitoring (Clause 6.2) This clause addresses monitoring requirements to support containment assurance. Only very high-level guidance is provided. The monitoring program shall address potential leakage pathways, and describe tools, methods, applicability, and frequency for detecting and quantifying losses.	**Some detailed guidance** The following monitoring is required: - Monitoring of the nature of injected fluids at time intervals sufficiently frequent to yield data representative of their characteristics; and - At least monthly (for EOR operations) measurement of injection pressure, flow rate, and cumulative volume. Monitoring can be on a field or project basis rather than on an individual well basis by manifold monitoring. Monitoring to document absence of CO_2 leakage or for detection and quantification of leakage is not required.
Well construction and well intervention Operators are required to provide evidence that wells are designed, constructed, and tested to provide safe, long-term containment of CO_2. To this end, well materials, including metals, cements, and elastomers, must be selected based on their ability to withstand the expected operational environment including the thermomechanical stress of operation and the geochemistry (including CO_2 where present) of the subsurface.	**Alignment, but much more detailed (prescriptive) guidance** The rule specifies that all new Class II wells shall be sited in such a fashion that they inject into a formation which is separated from any USDW by a confining zone that is free of known open faults or fractures within the area of review, and constructed such that injection will not result in the movement of fluids into an USDW so as to create a significant risk to the health of persons. The rule further specifies specific requirements for the construction, as well as to conducting appropriate logs and other tests during drilling and construction.
Quantification (See Section 2.5.2)	**Not covered by Class II rules**
Project termination (Clause 10) This clause contains specific guidance on the criteria for termination of a CO_2 EOR project, and the qualification process for demonstrating conformity with these criteria. This includes plans for plugging & abandonment of wells and decommissioning of facilities. The criteria for termination is broadly aligned with the requirements under Class II rules, but ISO 27916 considers the full EOR complex and demonstrating that there will not be future leakage from the EOR complex.	**General alignment** The owner or operator shall close the well in a manner that prevents the movement of fluid containing any contaminant into an USDW. Prior to granting approval for the plugging and abandonment of a Class II well the Director shall consider the following information: - The type, and number of plugs to be used; - The placement of each plug; - The type, grade, and quantity of cement to be used; and - The method of placement of the plugs;

[4] The US EPA's Underground Injection Control (UIC) program is designed to protect underground sources of drinking water. Under this program, Class II wells have been designated as those which inject fluids associated with oil and natural gas production.

[5] For class II wells the AoR is defined by a fixed radius around a well. This is in contrast to the EOR complex concept, and Class VI wells requirements, where the AoR is defined as "the region surrounding the geologic sequestration project where USDWs may be endangered by the injection activity".

2.5.2 Reporting of CO_2 emissions stored for tax credits under 45Q regulation

The US Internal Revenue Service's Internal Revenue Code section 45Q (US Department of Treasury, Internal Revenue Service, 2021) enables the application for tax credits by reporting of CO_2 sequestration. Taxpayers that claim the tax credit of section 45Q are to follow the appropriate UIC (Underground Injection Control) requirements (for Class II or Class VI wells) and follow the guideline in Subpart RR of EPA's 40 CFR Part 98: Geologic Sequestration of Carbon Dioxide under the US EPA program for mandatory reporting of greenhouse gases (U.S. EPA, 2016). However, in the new rule taxpayers operating a CO_2 EOR project can elect to report volumes of CO_2 stored pursuant to ISO 27916, provided documentation is certified by a qualified independent engineer or geologist. The documentation must include the mass balance calculations, and information regarding monitoring and containment assurance.

Both Subpart RR and ISO 27916 require annual reporting of stored CO_2 and provides mandatory calculations of CO_2 mass that is input to the EOR operations and any CO_2 mass that is lost during the CO_2 cycle in EOR operations. The ISO 27916 and Subpart RR calculation requirements differ in the specification of what and where CO_2 input and loss are to be calculated. The calculation of CO_2 mass that can be registered as sequestrated CO_2 is summarized and compared for ISO 27916 Clause 8 and Subpart RR of the CFR 40 in this section.

The terms that comprise the CO_2 mass sequestration equation are summarized in Table 2-4.

Table 2-4: Summary of CO_2 sequestration calculation as in ISO 27916 and Subpart RR of EPA's 40 CFR

ISO 27916 Clause 8	Subpart RR	Key differences
General CO_2 sequestration/storage mass equation		
$m_{stored} = m_{input} - m_{loss}$		**The starting point of the equations:** ISO 27916 starts the quantification of CO_2 mass stored at total CO_2 received at the EOR project complex/facility. Subpart RR starts quantification of CO_2 mass stored at injection flow meter. **Required measurement interval:** Subpart RR requires quarterly calculation of m_{input} and m_{loss}, added together to achieve annual reporting. ISO only requires annual reporting without other specifications for intervals.
CO_2 input		
m_{input} $= m_{received} + m_{native}$	m_{input} $= m_{injected}$	**Native CO_2[6]:** ISO 27916 includes native CO_2 in CO_2 input – if authorities allow it. In Subpart RR native CO_2 is excluded from CO_2 input by subtracting all CO_2 produced. Thus, native CO_2 is not a part of the calculated CO_2 stored.
CO_2 loss		
m_{loss} $= m_{transferred}$ $+ m_{loss\ leakage\ facilities}$ $+ m_{loss\ vent/flare}$ $+ m_{loss\ entrained}$ $+ m_{loss\ transfer}$ $+ m_{EOR\ complex}$	m_{loss} $= m_{loss\ produced}$ $+ m_{loss\ equipment\ leakage/vent}$ $+ m_{loss\ surface\ leakage}$	**Transferred CO_2:** In Subpart RR transferred CO_2 is not included in CO_2 mass storage equation. This is a consequence of the starting point of the quantification equation. ISO 27916 subtracts transferred CO_2 to other facilities from the CO_2 received. **Specification of losses:** The ISO 27916 requirements to quantification of CO_2 losses are in overall more general, while Subpart RR specifies loss quantification at certain points in the cycle of the CO_2 during EOR operations.

[6] CO_2 present and indigenous within the project reservoir prior to hydrocarbon production or any CO_2 injection.

Table 2-5: Comparison of each CO_2 loss and input component as specified in ISO 27916 and Subpart RR (see also Figure 2-1 and Figure 2-2).

Component	ISO 27916	Subpart RR
Received	$m_{received}$ CO_2 mass received	CO_2 mass received – CO_2 mass transferred to other facility at reception *(Mandatory to report but is not a part of CO_2 sequestration mass equation in Subpart RR. CO_2 received is covered in Subpart UU.)*
Added Input	$m_{input} = m_{received} + m_{native}$ $m_{received}$: CO_2 mass received m_{native}: CO_2 mass that is native	$m_{input} = m_{injected}$ CO_2 mass injected into the subsurface
Loss Transfer	$m_{loss\ transfer}$ Any CO_2 mass that is transported out of the facility without being injected.	- Does not calculate specifically the mass of CO_2 that is produced at the facility and then transported instead of recycled. All CO_2 that is produced and separated is evaluated as loss.
Loss Produced	$m_{loss\ entrained}$ CO_2 mass entrained in gas/oil/water that is not separated and then not reinjected.	$m_{loss\ produced}$ All **CO_2 mass separated** from produced flow through separators + **CO_2 entrained in oil/fluid after separation** (measured CO_2 separated multiplied a percentage of CO_2 to remain entrained, this percentage is to be estimated in the MRV plan). Thus, it is ensured that the native CO_2 as well as the CO_2 not injected is subtracted from the CO_2 input.
Loss Leakage (EOR complex vs surface)	$m_{EOR\ complex}$ All CO_2 mass leaked from EOR complex (EOR complex: *reservoir, trap, and additional surrounding volume in the subsurface where CO_2 is injected for long term storage*)	$m_{loss\ surface\ leakage}$ Total CO_2 mass emitted by surface leakage from all pathways.
Loss Project Operations	$m_{loss\ leakage\ facilities} + m_{loss\ vent/flare}$ $m_{loss\ leakage\ facilities}$: All CO_2 lost from facilities (including wellheads), thus all CO_2 leaked from production, handling and recycling CO_2-EOR facilities. $m_{loss\ vent/flare}$: Mass of CO_2 lost due to venting or flaring in production operations: total of CO_2 released through the flare line (excluding products from combustion)	$m_{loss\ equipment\ leakage/vent}$ Total mass of CO_2 leaked or vented from equipment that is located on the surface between injection flow meter and injection wellhead, or between production wellhead and production flow meter.

*Green cells = more detailed calculation than the equivalent component in the other standard.

The calculations involved in the mass balance equations to determine the volume of sequestered CO_2 is for ISO 27916 and the RR rule visualized in Figure 2-1 and Figure 2-2 respectively. To the knowledge of the authors of this report, the 45Q tax regulation is the only regulatory guidance document that makes explicit mention of ISO 27916.

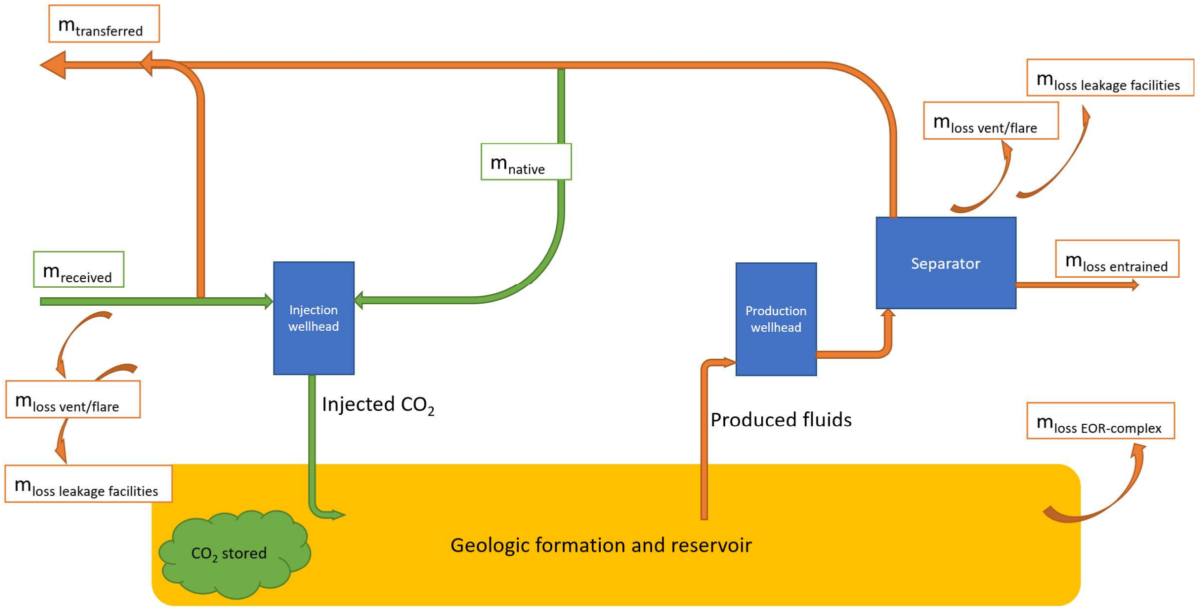


Figure 2-1: Simplified drawing of the components in the CO_2 mass equation in ISO 27916

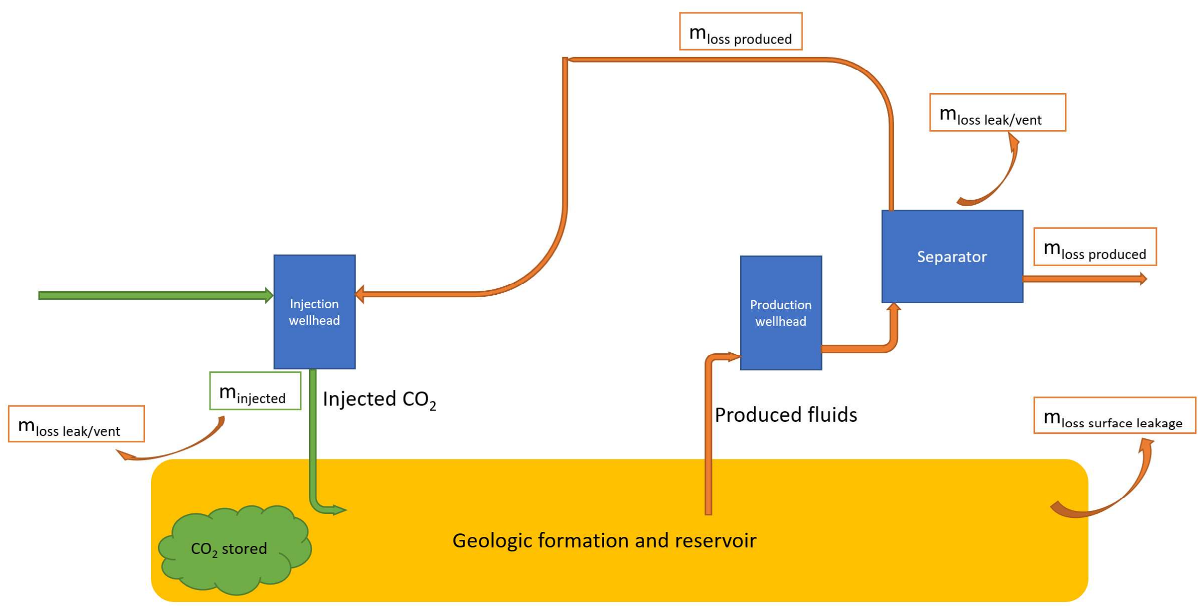


Figure 2-2: Simplified drawing of the components in the CO_2 mass equation in Subpart RR

3 APPLICABILITY TO SUPPLEMENT EXISTING REGULATIONS

In this section we will assess and describe how the standards may be used to supplement to existing regulations. We will focus specifically on how ISO 27914 might be applied to support permitting of CO_2 storage sites in regions that have introduced tailored regulations for geological storage of CO_2, and how ISO 27916 may be applied for crediting and/or accounting purposes to supplement to existing rules under regulated systems.

3.1 Application of ISO 27914 to support storage site permitting

For CO_2 geological storage, broadly four different permits are relevant (although there are variations to this by country, state or province, such as in Australia where the Declaration of Storage Formation is supplementary):

- **An exploration or evaluation permit**, giving exclusive rights to perform certain studies and physical tests to evaluate the suitability of a prospective storage site. This may include drilling of wells and injection of substances and seismic surveys.
- **A storage permit or sequestration lease**, that provides the proponent the rights to use a given storage site for geological storage of a prescribed amount of CO_2 under specified development and operating conditions. This includes the right to develop necessary infrastructure, drill wells, conduct evaluation and testing, and as a prelude to injecting CO_2.
- **An injection permit**, giving the proponent the right to commence injection operations and determines the conditions that must be met by the operator during the operation. This generally includes reporting requirements, approved plans for monitoring, measurement and verification, conditions for site closure and handover of site responsibility, and plans for post-injection site care to demonstrate conformity with site closure conditions.
- **Closure certificate and transfer of responsibility**, if relevant in the jurisdiction.

As indicated in Section 2.1, ISO 27914 does not provide explicit guidance on permitting requirements. Furthermore, the structure of the technical content in ISO 27914 is not organized to follow the project life-cycle of a CO_2 storage project. For instance, the clauses on *Management systems, Risk management,* and *Monitoring and Verification (M&V)* are relevant for all phases of the project, and requirements to the clause on *Well infrastructure* also includes requirements to well abandonment. To argue compliance with ISO 27914 at a given point in the project life-cycle as part of a permitting process, the proponent must first establish consensus with the relevant regulatory body on the requirements to be considered. Recognizing the hurdle, DNV mapped in DNV-SE-0473 (DNV, 2017a) requirements and recommendations in ISO 27914 according to the following key decision gates in the project life-cycle:

- Site selection (exploration permit)
- Investment decision (technical basis for storage permit)
- Storage permit application
- Commencement of operation (injection permit)
- Operations (injection period)
- Site closure (conformance with technical criteria for transfer of responsibility)

This document can therefore be used alongside to inform a discussion between project proponents and the relevant regulatory authority about the requirements in ISO 27914 that should be considered at different stages of the life-cycle of a CO_2 storage project, and at stages where regulatory permits are required.

To provide more tangible examples of how ISO 27914 can support storage site permitting (in jurisdictions that have developed tailored regulation for CO_2 storage projects) we discuss below examples from Norway and Alberta, Canada. Norway has transposed the EU CCS Directive into national law in a way that broadly mirrors the regulation of oil and gas developments. A key part of the approval process is the development of a plan for development and operations

(PDO). Alberta has introduced the Alberta Carbon Sequestration Tenure Regulation. As part of these regulations, specific requirements apply for the issuance of a closure certificate for the carbon sequestration lease. In the following subsections we will discuss how ISO 27914 provides further guidance to project proponents and regulators that might facilitate approval of the PDO in Norway and issuance of a closure certificate in Alberta.

3.1.1 Use of ISO 27914 to support development and approval of PDO (Norway)

The Norwegian regulations for transport and storage of CO_2 on the Norwegian Continental Shelf (NCS) is a transposition of the EU CCS Directive into Norwegian law, and follows closely the EU CCS Directive (Norwegian Petroleum Directorate, 2014). Elements of the EU CCS Directive are also included in Part 7A of the Norwegian Pollution Control Regulations (Norwegian Ministry of Climate and Environment). Prior to commencement of the injection operations, the following regulatory approvals are required:

- Permit for exploitation of a sub-seabed reservoir for injection and storage of CO_2;
- Approval of plan for development and operation (PDO); and
- Permit for injection and storage of CO_2.

ISO 27914 may be particularly useful to assist in developing the PDO. Table 3-1 identifies the requirements in ISO 27914 that provide relevant guidance for the information that must be included in the PDO.

Table 3-1: Overview of technical criteria for PDO and associated clauses in ISO 27914

Requirement		Clause in ISO
a)	Characterization of storage site and complex and storage risk assessment	5.4-5.5, 6.7
b)	Description of injection strategy and proposed site development, and criteria for project decisions	7.3, 7.5, 8.2-8.5
c)	Description of • geoscientific and reservoir circumstances, • total volume of CO_2 to be injected and stored, • expected CO_2-sources and methods of transport, • rate of injection and pressure circumstances, • injection facility locations	5.4-5.5
d)	Composition of CO_2-stream	8.2.4.2
e)	Description of technical solutions with expected energy consumption and access, including measures to prevent significant irregularity	6.6-6.8
f)	Description of management systems, including information about planning, organization and execution of the development of the storage site	4
g)	Information about operation and maintenance	8.2-8.5
n)	Proposed monitoring plan	9.3-9.4
o)	Proposed plan for corrective actions to significant irregularities	6.6 and 6.8
p)	Proposed plan for post injection site care	10.3

In addition, an Environmental Impact Assessment (EIA) is required to be submitted as part of the application for approval of the PDO. The EIA builds on site characterization (Clause 5), risk management (Clause 6), and monitoring (Clause 9), and also depends on material selection and infrastructure design described in Clause 7.

3.1.2 Use of ISO 27914 to support evaluation of closure requirements (Alberta)

In accordance with the *Alberta Carbon Sequestration Tenure Regulation* (Alberta Government, 2011) and *Bill 24 - Carbon Capture And Storage Statutes Amendment Act* (Alberta Government, 2010), the liability associated with a CO_2 storage project in the province will be transferred to the Government of Alberta when a closure certificate is issued and the operator has met its obligations.

The Alberta Regulatory Framework Assessment (Alberta Government, 2013) recommended establishing performance criteria for closing a CO_2 sequestration site, including that the CO_2 is behaving as predicted, there are no significant risks to people or the environment, required closure activities have been carried out, and at least 10 years have passed since approval of the final closure plan. The Alberta Tenure Regulation requires that the (final) closure plan include the following performance criteria:

- an evaluation of whether the injected captured carbon dioxide has behaved in a manner consistent with the geological interpretations and calculations (to demonstrate site integrity);
- a description of the location, condition, plugging procedures and integrity testing results for every well that has been used for the injection of captured carbon dioxide (to demonstrate well integrity); and
- a description of any decommissioning, abandonment or reclamation activities undertaken (to meet requirements for decommissioning and removal of facilities and equipment associated with the storage project).

These criteria also broadly mirror the *criteria for site closure* in ISO 27914 (Section 10.2), as well as the *requisites for termination* in ISO 27916 (Clause 10.4). Unlike the EU (under the CCS Directive), the US (under the Class VI rule) and Australian Commonwealth, the province of Alberta has yet to prescribe a “closure period”. This implies that there is a lack of predictability in the province regarding the period during which the operator may need to continue monitoring and post-injection site care activities. This is also the case in the EU and the US where the timeframe for the period following the cessation of injection to closure (and transfer of responsibility and liability in the EU) is nominal, it leaves discretion to the competent authority (in the EU) and the “UIC Program Director[7]” in the US.

The demonstration of compliance with the *criteria for site closure* in ISO 27914 (Section 10.2), as well as the *requisites for termination* in ISO 27916 (Clause 10.4) may assist the project proponent to establish with the relevant regulatory body acceptable confidence that that injected CO_2 will be retained within the storage complex and that risk associated with the project are de minimis.

The Alberta Tenure Regulation further specifies that “A lessee shall pay into the Post-closure Stewardship Fund (PCSF) a fee per tonne of captured carbon dioxide injected into the location of a carbon sequestration lease […]”. The Alberta Regulatory Framework Assessment further recommends that Alberta should “set project-specific PCSF rates that cover the costs of long-term monitoring and maintenance, CO_2 credits liability, and costs associated with unforeseen events”. Hence, while the PCSF should pool payments from different projects to cover unforeseen costs from any project, the rate that each project should pay will be based on each project’s risk profile, and may differ from project to project.

DNV supported the Alberta Government (Alberta Department of Energy) in establishing the methodology for determining the rate that a project needs to pay per tonne of CO_2 injected (DNV GL, 2014). The PCSF shall cover:

- costs for monitoring, measurement and verification (MMV) activities post-closure;
- costs for any mitigation, remediation and reclamation activities associated with residual risks after closure;
- costs associated with suspension, abandonment and related reclamation or remediation of orphan facilities; and
- costs associated with administration of the PCSF fund.

[7] The person responsible for permitting, implementation, and compliance of the UIC program.

The proposed methodology is generic, but requires project specific inputs. This includes an updated assessment of residual risk. Prior to transfer of liability, the operator should demonstrate that *"the project-specific risk profile is decreasing and the risk of future leakage or adverse effects on health, the environment or other resources is acceptable"*[8]. ISO 27914 provides guidance on risk assessment and on documentation of risk. Adherence to this guidance can be effective to help operators provide confidence with Alberta Government officials involved in determining the PCSF rate that risk has been assessed and quantified in accordance with best industry practice.

The Alberta Tenure Regulation also stipulates that the closure plan shall contain "*advice and recommendations about the monitoring, measurement and verification activities that should be conducted after a closure certificate is issued for the carbon sequestration lease*." While ISO 27914 does not provide guidance for the post closure (post liability transfer) period, a general reflection is that such MMV activities are presumed unnecessary by ISO 27914. In the standard, the purposes of MMV are (1) to assist in managing health, safety, and environmental risks, and (2) to assess storage performance. The emphasis of the ISO 27914 MMV guidance is on supporting risk management. Since a closure certificate can only be issued if the residual risk is deemed acceptable without active further risk controls[9], no further MMV should be needed to manage risk. Therefore, the required post-closure MMV is principally a mechanism to provide assurance to the public that the storage sites retain their integrity after closure, and not to address technical risk.

3.2 Application of ISO 27916 to support emission accounting

ISO 27916 Clause 8 establishes methods and requirements for quantification of mass of CO_2 stored and lost associated with CO_2-EOR operations. The clause specifies how native CO_2 can be included and how to determine the anthropogenic part of CO_2 stored and emitted. Some governments and international organisations have also developed guidelines for calculating CO_2 emitted or emission reductions associated with carbon capture and storage.

The USA 45Q tax regulation allows operators to receive tax credits for each metric ton (tonne) of qualified carbon oxide stored. CO_2 EOR operators in the US may select to quantify CO_2 emissions stored using the quantification methodology in ISO 27916, rather than the RR reporting rules (U.S. EPA, 2016). The RR rules, and also ISO 27916, are therefore focused on quantifying the amount of CO_2 stored, and not the GHG emission reductions that can be attributed to the project. ISO 27916 allows *native CO_2* to be included in the amount of CO_2 stored, provided this is accepted by the regulator. If this is accepted, then the operator can receive increased tax credits for their CO_2 EOR operation. This does not appear to be the case in the US under the 45Q tax regulation, but as it may represent a key motivation for reporting in accordance with ISO 27916 (which also comes with a requirement for third party certification) rather than the RR rules, this can be subject to clarification for the first projects considering opting to apply ISO 27916.

To assess how ISO 27916 might be applied for CO_2 accounting purposes as a supplement to other regulations, we have compared it to four guidelines for accounting CO_2 emissions for CCUS projects. The comparison focuses on the scope and purpose of the documents as well as the quantification of stored and emitted CO_2.

The quantification methodology in the following protocols and guidelines are synthesized and compared in Table 3-2:

1. **ISO:** ISO 27916
2. **EU:** EU Monitoring and Reporting Guidelines (MRG) (European Commission, 2010).
3. **California:** California Air Resources Board – Carbon capture and sequestration protocol under the Low Carbon Fuel Standard (LCFS) (California Air Resources Board, 2018).

[8] Recommendation 63 of Alberta Regulatory Framework Assessment, (Alberta Government, 2013).

[9] Measure whose purpose is to reduce a specific risk or avoid escalation of risk.

4. **Alberta:** The Alberta quantification protocol for CO_2 capture and permanent storage in deep saline aquifers (Alberta Government, 2015).
5. **Canada:** Canada clean fuel regulations: Quantification method for CO_2 capture and permanent storage (Environment and Climate Change Canada, 2020).

The Canadian standards, number 4 and 5, are combined as their content is broadly equivalent.

All the above quantification protocols are informed by the 2006 IPCC Guidelines for National Greenhouse Gas Inventories guidance for CCS projects in Chapter 5 of Volume 2: Energy (IPCC, 2006). The rationale for comparing ISO 27916 to the above regional implementations, rather than the 2006 IPCC Guidelines, is that there are some notable differences between them, and that ISO 27916 is to a greater degree informed by the EOR practice in the United States and by the reporting rules under Subpart RR (U.S. EPA, 2016). In particular, the regional quantification protocols and guidelines are developed to support inclusion of emission reductions from CCS projects in regional programs providing credits for emission reductions, whether this is in the form of a cap-and-trade scheme or a tax-credit system. The purpose of the different protocols is explained below as part of a discussion on the applicability of ISO 27916.

Each of the quantification protocols considered in Table 3-2 below can be applied to secure credits related to CO_2 emission reductions. However, the method of quantification is different and serves different purposes. We now briefly discuss the possible applicability of ISO 27916 as a supplement to these protocols.

- Under the EU Emission Trading Scheme (ETS), owners of CO_2-emitting industrial facilities need to surrender allowances for each tonne of GHG emitted. These facilities can potentially deploy CCS to *reduce the number of allowances* they need to surrender, and hence reduce costs. The emissions from the full CCS value chain must be determined and reported in accordance with the EU monitoring and reporting guidelines (MRG). These guidelines therefore focus on the resulting emissions, and not on the amount of CO_2 stored. For geological storage projects, the amount of CO_2 stored may be calculated by taking the amount of injected CO_2 minus “leakage from the storage complex”, but operators do not get credits for the amount of CO_2 stored. The EU MRG points to additional emission sources for hydrocarbon recovery operations with CO_2 injection, but does not describe the quantification method in detail. ISO 27916 can therefore potentially be used as a supplement to the EU MRG for hydrocarbon recovery operations to inform regulators and stakeholders about the amount of CO_2 stored associated with these operations.
- The California LCFS, as well as the Canadian Clean Fuel Regulations and the Alberta quantification protocol for CO_2 capture and permanent storage in deep saline aquifers, are all set up to allow calculation of GHG emission reductions from CCS projects. The California LCFS includes CO_2 EOR, the other two protocols do not. All of these protocols provide guidance on calculation of CO_2 (or GHG emissions) reductions, which includes calculating stored CO_2. ISO 27916 can therefore be used as a supplement to the California LCFS CCS protocol to inform regulators and stakeholders about the amount of CO_2 stored associated with CO_2 EOR operations. However, since ISO 27916 *does not apply to quantification of CO_2 injected into reservoirs where no hydrocarbon production is anticipated or occurring*, it is not envisioned that it will be applied to supplement the Canadian protocols.[10]

[10] There is now a plan to include quantification of emissions as part of the revision of ISO 27914. When (if) this is completed, the updated standard may potentially be applied to supplement the Canadian protocols and the LCFS for project with dedicated CO2 storage and no hydrocarbon recovery is anticipated.

Table 3-2: Comparison of CO_2 quantification requirements associated with CO_2 storage operations

ISO	EU	California	Alberta, Canada
Focus: ✓ Quantification of net **stored** CO_2. **Purpose:** Standardized methods for quantifying CO_2 stored and lost, and the anthropogenic portion of the CO_2 associated with the CO_2-EOR process. Scope excludes application to CO_2 storage projects without hydrocarbon production, but elements of quantification methodology can be applied also to CO_2 storage.	**Focus:** ✓ Quantification of **emitted** CO_2. **Purpose:** Requirements to quantification of GHG emissions for reporting under the EU Emissions Trading System (ETS). Applicable to both CO_2 storage projects and enhanced CO_2 hydrocarbon recovery projects.	**Focus:** ✓ Quantification of net **GHG emission reductions**. **Purpose:** Methodology for estimating GHG emission reductions (CO_2, N_2O, CH_4, CO and VOC) due to CCS to help meet benchmarks and enable LCFS credits. Applicable to both CO_2 storage projects and enhanced CO_2 hydrocarbon recovery projects.	**Focus:** ✓ Quantification of net **GHG emission reductions**. **Purpose:** Methodology for estimating GHG emission reductions (CO_2, CH_4 and N_2O) to meet benchmarks and generate credits. Not applicable to CO_2 EOR or acid gas injection.
Quantification of stored CO_2: CO_2 stored in association with CO_2-EOR shall be quantified by determining input CO_2 and subtracting loss of CO_2 from the CO_2-EOR project. Native CO_2 can be included in the CO_2 input. The anthropogenic part of the CO_2 can be quantified.	**Not aligned.** The EU MRG does not provide calculation methods for quantification of stored CO_2.	**Somewhat aligned.** Explicit calculation of GHG reduction, corresponding to CO_2 stored. Emission reductions are determined by injected CO_2 minus GHG emissions from the CCS project. For CO_2 EOR, injected CO_2 excludes recycled CO_2. Native CO_2 is not accepted.	**Somewhat aligned.** Explicit calculation of emission reduction, corresponding to CO_2 stored. Emission reductions is equal to injected CO_2 minus GHG emissions from the CCS project, where injected CO_2 is measured directly upstream of the injection wellhead. CO_2 EOR is excluded.
Quantification of CO_2 lost: CO_2 lost from CO_2-EOR recycling facilities, production, handling, from venting/flaring during production operations, leakage from storage complex, entrained CO_2 in produced fluids and CO_2 transferred out of the facility.	**Overlapping.** The loss of CO_2 is referred to as CO_2 emissions that are required to be included in the greenhouse gas emission permit. This includes emissions from CO_2 capture, CO_2 transport by pipelines, CO_2 storage, CO_2 transferred and emitted, and CO_2 emissions from enhanced hydrocarbon recovery. The maximum allowed uncertainty of the quantification of emission amounts over the reporting period is +/- 7.5%. In case the overall uncertainty exceeds this percentage, a penalty shall be applied in the emission quantification.	**Overlapping.** Annual greenhouse gas emissions related to CO_2-EOR must be calculated. This includes emissions from CO_2 capture, dehydration, compression transport, and storage, as well as embodied lifecycle GHG emissions from use of electricity, steam and fuel.	**Overlapping.** Annual greenhouse gas emissions from CO_2 capture and storage, as well as embodied emissions from offsite heat and electricity generation, delivery of materials used in CO_2 capture processes, and loss, disposal or recycling of materials used in CO_2 capture processes.

4 CASE STUDIES – APPLICATION IN REAL PROJECTS

The intent of this section is to provide insight into how the standards – ISO 27914 and ISO 27916 – have been used in guiding real life projects. We will also consider specific examples of current practices and evaluate how they compare to the related requirements in ISO 27914 or ISO 27916. For this, we will draw upon DNV experience and information in ISO DTR 27923 Geological storage of carbon dioxide injection operations and infrastructure (ISO, 2021). Specifically, we will consider the following three case studies:

1. How were DNV-RP-J203 and ISO 27914 used to determine site feasibility for CO_2 storage for the CarbonNet Project (Victoria, Australia) and Project Greensand (Denmark) respectively?
2. What elements of ISO 27914 can be applied to guide re-qualification of wells at CO_2 storage sites (CO_2 injection wells, brine production wells, monitoring wells, and plugged and abandoned wells)? How has DNV deployed re-qualification processes to assess the possibility of re-using wells for oil and gas developments?
3. To what extent are the M&V plans developed for the Shell's QUEST CCS project and the CO_2 EOR operations by Oxy at the Denver and Hobbs field, which are reporting under the EPA RR rules, aligned with the guidance provided on M&V in ISO 27914 and in ISO 27916, respectively. And to what level would these standards provide guidance on development of similar plans for future projects.

4.1 Case Study 1 – Determine site feasibility for CO_2 storage

DNV has provided independent review and certification of site feasibility[11] for two projects – the CarbonNet Project offshore Victoria, Australia, and Project Greensand offshore Denmark. The feasibility of prospective sites for the CarbonNet Project was determined through application of the certification framework DNV-DSS-402 (DNV, 2012), which involves verification of requirements for the site screening stage in the recommended practice DNV-RP-J203. The feasibility of the site for Project Greensand was determined through application of the certification framework DNV-SE-0473, which involves verification of requirements for the site screening and selection in ISO 27914. We will in this section describe both verification processes and provide a comparative analysis to highlight some key differences.

4.1.1 The CarbonNet Project site feasibility assessment

DNV issued a Statement of Feasibility to the CarbonNet Project in January 2013 following a verification of requirements for site screening in DNV-RP-J203. The statement was issued for a portfolio of three sites within the Gippsland Basin, signalling that at least one of the sites, or a particular combination of the sites, meets the conditions for issuance of the Statement of Feasibility.

The requirements to site feasibility build on the process laid out in the CO2QUALSTORE guideline (DNV, 2010), as shown in Figure 4-1. Evaluation of feasibility includes an evaluation of both the pre-feasibility steps and the feasibility steps. A key component of the feasibility assessment was the definition of transparent criteria in the screening basis that will be used to evaluate the suitability of the candidate sites to meet the project objectives. DNV-RP-J203 prescribes some criteria that *should* be included in the screening basis (Table 4-1 in DNV-RP-J203), but the criteria can be further refined and detailed to reflect project conditions. Other criteria are defined based on the local and regional context, e.g. with respect to the natural and regulatory environment, the local population and other uses of the subsurface. Compliance with the criteria in the screening basis should provide confidence that further site appraisal would provide the information and evidence needed to compile a robust storage permit application.

[11] A storage site at an early stage of development is considered conceptually feasible if the main challenges have been identified and judged to be resolvable by use of sound engineering practice (DNV, 2017a).

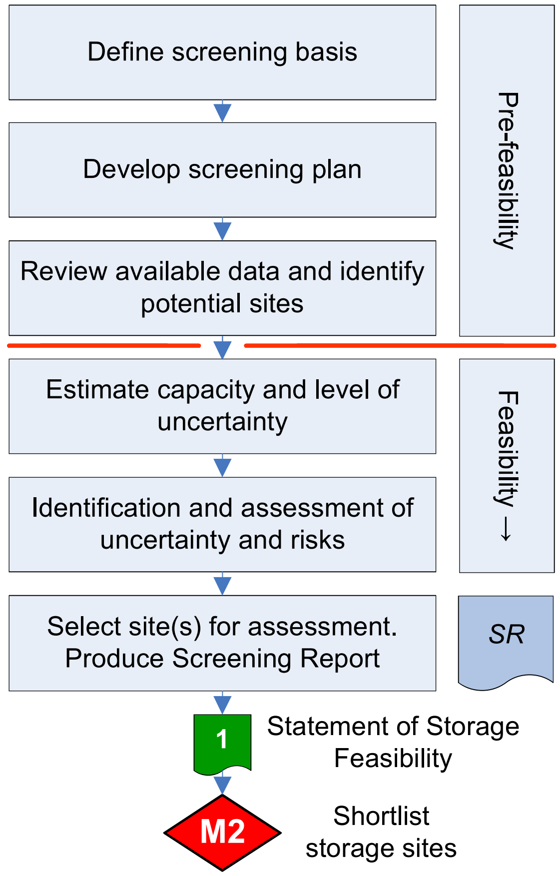


Figure 4-1: Process for site screening in DNV-RP-J203, from the CO2QUALSTORE guideline.

The CarbonNet Project screening basis defined a total of 20 different screening criteria to be applied to all three sites evaluated. The screening basis included technical criteria related to the geologic suitability of the candidate storage sites, and commercial, social, environmental, and regulatory criteria related to site access, proximity to sources, land use, social and cultural context and the legal and regulatory environment. The criteria were described with a level of detail and precision to enable an objective and unambiguous evaluation of each criterion.

For each of these criteria, we used green, yellow and red colours to indicate the level of compliance with the site screening criteria[12]. The colouring also enabled a visual comparison of the evaluated suitability of the sites and areas of potential concern. The portfolio of sites was found to be feasible if at least one of the sites did not have any non-compliant (red) criteria, or there was a combination of sites that combined would not have any red-coloured criteria.

Another core component of the verification of feasibility in accordance with DNV-RP-J203 is that it puts emphasis on documenting risk and uncertainty assessment at the site screening stage, and that this is compiled into an initial risk register. In the uncertainty assessment, the emphasis is on showing that the quality and quantity of the available evidence enables an objective assessment of the requirements laid down in the screening basis. The initial risk register, and screening report documenting the basis for the evaluation of the risks in the risk register, should provide sufficient information on project risks to be suitable for independent audit and verification.

[12] Green signalled high level of confidence that a criterion is met for the associated site. Yellow signalled that there exists an issue of material concern for the criterion that merits further attention, should the site be selected for further appraisal. Red signalled that the criterion is not considered to be met for the site.

4.1.2 Project Greensand

DNV issued a “Certificate of conformity – site feasibility” to Project Greensand after evaluating conformity with the requirements to site screening and site selection in Clause 5.2 and 5.3 of ISO 27914. DNV also evaluated the conformity of the initial risk register and implementation of process for risk management with ISO 27914.

ISO 27914 does not explicitly describe the documentation that needs to be provided to document adherence to the recommendations to site screening and selection. The key recommendation is that “*potential storage sites should be screened and ranked according to the key technical and legal and regulatory criteria*” listed in Clause 5.2. ISO 27914 also prescribes subsurface and surface criteria that should be assessed for sites that have passed the screening stage, and states that this assessment *should* result in a list of selected potential sites for further characterization.

There are no mandatory requirements (shall statements) to be evaluated for feasibility. All criteria listed in both 5.2 and 5.3 are recommendations (should statements). This implies that if a criterion is not evaluated or considered, it needs to be considered if that requirement is relevant for the project. To this end, the project proponent is required to explain why the relevant recommended criterion is not evaluated, unless this is obvious from the context.

The target storage site for Project Greensand is a depleted oil field that is part of an existing license held by INEOS E&P and Wintershall Dea. To evaluate conformity with ISO 27914, the storage complex and operational limits were described in a screening report with a series of appendices. This information included license ownership, site location and accessibility, environmental impact potential, geological context, existing infrastructure and wells, evaluation of storage site capacity, injectivity and containment, operational parameters such as target injection rates and bottom hole pressure constraints, monitoring principles, and an initial project risk register.

When evaluating the requirements in ISO 27914, DNV provided a rationale for the evaluation of conformity or why the requirement was not relevant. This rationale also provides a description of the pieces of evidence supporting the conclusion. DNV also sometimes pointed to studies that would need to be performed in further work, e.g. to validate assumptions or conclusions that at this stage in the project are not fully supported by available evidence.

4.1.3 Comparative analysis

A key difference between the evaluation of site feasibility using the two standards DNV-RP-J203 and ISO 27914 lies in the definition of the screening (and site selection) requirements to be evaluated.

Certification against DNV-RP-J203 (Section 4.2) largely follows an approach where a project specific screening basis is defined to reflect the applicable circumstances, and the verification seeks to check if the documentation provided provides the necessary evidence to establish confidence that the requirements in the screening basis have been met.

Certification against ISO 27914 (Clause 5.2 and 5.3) on the other hand is dictated by the requirements listed, and the project proponent must provide evidence to support that each requirement is either met or not relevant. While the approach to evaluate each requirement is similar to the evaluation of the screening basis for DNV-RP-J203, there is somewhat less freedom to tailor the ISO 27914 requirements to project specific circumstances. For instance, a number of the requirements in ISO 27914 are only relevant for onshore storage sites, and hence not relevant for Project Greensand. Furthermore, there was less freedom to formulate the requirements in a way that it can be unambiguously interpreted for the relevant site. Some of the “criteria” in ISO 27914 are quite vaguely defined. This applies for instance to *cultural and historical resources* and *socio-economic conditions,* which are two of the surface criteria to be assessed during the site selection stage for sites that passed the site screening stage.

Hence, from our experience with these two projects we found it to be easier to provide independent verification of requirements in a screening basis that are specifically tuned to project circumstances.

Both ISO 27914 and DNV-RP-J203 require the creation of an initial risk register during the site screening stage, but DNV-RP-J203 has more emphasis on the risk and uncertainty assessment. The evaluation of the screening basis and related uncertainties also informs the studies that should be performed in further site characterization work to confirm suitability of the prospective sites. A requirement in DNV-RP-J203 is to identify and record critical pieces of missing information that would reduce the uncertainty for a given storage site to be used in developing an eventual appraisal plan. There is no requirement in the relevant clauses of ISO 27914 (5.2 and 5.3) that specifically aims to identify uncertainties at the site screening and selection stage that need to be assessed in further work[13].

4.2 Case Study 2 – Re-qualification of wells at CO_2 storage sites

Case Study 2 focuses on the re-qualifications of wells[14], and illuminating how existing standards and previous work in CO_2 storage projects can provide guidance for re-use and proper re-qualification of wells for CO_2 storage purposes.

A recommendation to use ISO 27914 Section 7.6 (as well as DNV-RP-J203 Section 7) to guide well re-qualification is made in the Norwegian CO_2 Safety Regulation Section 11 (Petroleum Safety Authority Norway, 2020a) and the corresponding guidelines (Petroleum Safety Authority Norway, 2020b). Additional relevant standards include ISO 16530 (ISO, 2017b), NORSOK D-010 (Standards Norway, 2021a), NOGEPA 45 (NOGEPA, 2018a) and 51 (NOGEPA, 2018b), NOROG 117 (Norsk olje&gass, 2013), API/TR 10TR1 (API, 2008), RP 90 (API, 2006), RP 65-2 (API, 2010) and Oil and Gas UK guidelines (Oil and Gas UK, 2015) are well integrity and well design principles for the Oil and Gas industry. The principles described in these standards apply fully to CO_2 storage wells including re-use and re-qualified wells.

In Section 4.2.1 we compare and contrast the guidance related to re-qualifying wells provided in ISO 27914 with the process and requirements laid out in DNV-RP-J203. We then, in Section 4.2.2, we provide observations from two projects where re-qualification of wells was performed. One of these were the Kingsnorth UK project. The second project involved assessing well performance for isolation and abandonment purposes for a large European operator.

4.2.1 Well re-qualification guidance in ISO 27914 and DNV-RP-J203

The Norwegian CO_2 Safety Regulation touches on the need for re-qualification of wells for CO_2 storage, and refers to ISO 27914 and DNV-RP-J203. These two standards deal with this issue differently, and somewhat complementary. Table 4-1 compares the guidance provided for well re-qualification of ISO 27914 and DNV-RP-J203.

Table 4-1: Comparison of ISO 27914 and DNV RP J203 towards well re-qualification.

Topic	ISO 27914	DNV-RP-J203
Well design	Clause 7.3.3.2 focuses on the design of new wells	Built into re-qualification evaluation in Clause 7.2 to 7.11
Tubulars, casing and conductor design	Clause 7.3.4 describes functional requirements for tubulars	Clause 7.2 to 7.11 covers a risk-based, threat identification and assessment process, where the cross-disciplinary team identifies and assesses the applicability and level of fit-for-purpose of the well system.
Completion design	Clause 7.4.1 identifies the alignment of the completion design and project goals	
Cementing design	Clause 7.4.2 describes the performance for cement in CO_2 wells	
Material selection	Clause 7.2 describes material design and capability	

13 Clause 6.3 states that "the process for risk management should be implemented during the initial site screening, selection, and characterization periods …", which includes evaluating "uncertainty that can influence the performance of the storage project".

14 Well qualification is the process of providing the evidence that a given well will function within specific limits with an acceptable level of confidence. Re-qualification of wells means assessing if wells can be qualified for another purpose than it was initially designed (and qualified) for.

Wellbore integrity	Clause 7.7.3 highlights the importance of well integrity to prevent leakages along the wellbore	
Annulus pressure management	Clause 8.4.2.3 describes operational protocols for annulus observation and management	Clause 7.2.2 describes pressure operational limits and Appendix A and B providing examples into the risk assessment process
Re-completion and workover	Clause 7.6 outlines the objectives of workover of legacy well to determine their status, integrity and appropriateness for use.	Clause 7.2 to 7.11, specifically 7.10, where workover data can provide additional evidence to the performance assessment of the well re-qualification.
Well abandonment	Clause 7.8.3 describes the demonstration of the wells' abandonment performance and isolation integrity prior to abandonment Clause 10.2(d), 10.3(d), and 10.4.1(d) also address well abandonment and risk reduction	Clause 7.1 covers functional requirements for abandonment
Competence requirement for well qualification	Clause 4.5.2 on general CCS competence scheme	Table 7-1 highlights well specific competence recommendations.
Documentation of adherence to well qualification or re-qualification performance	Project specific, not detailed in ISO 27914	Final well (re)qualification report

In both ISO 27914 and DNV-RP-J203, the duty of the operator is to identify suitable well barriers throughout the life cycle of the well is provided (REX-CO2, 2020). The choice of materials and their selection, installation, verification, testing and maintenance should also be documented, and the well barriers should be tested and documented. The well integrity risk assessment should include the following aspects:

- Maximum differential pressure across barriers throughout the life cycle
- Potential fluid chemistry
- Criteria for success (of a pressure test)
- Criteria for failure (of a pressure test)
- Contingency plans if the barrier could not be tested

ISO 27914 Section 7.6 provides guidance on what physical mitigation measures can be carried out to assess and evaluate the technical status of the wells' integrity relative to CO_2 storage. Additional guidance is provided for legacy wells which in ISO 27914 are defined as *pre-existing well(s) within the area of review of a CO_2 storage project that was/were drilled for a different purpose than CO_2 injection or monitoring of the respective CO_2 storage project*. Re-using or re-qualifying wells for CO_2 is based on an assessment and evaluation of the wells to leak or experience unwanted cross-flow. Details as to how to perform the assessment according to ISO 27914, section 7.6 are not provided, and the guidance is on a higher level describing what threats should be considered for well re-use and re-qualification.

DNV-RP-J203, Section 7 provides recommendations for performing well qualification for CO_2 storage. The well qualification process applies for both new and existing legacy wells. The process is a risk-based technology qualification approach, where identifying risk and threats to future performance and reliability of the well(s) is a key element. Upon the completion of well qualification / re-qualification, a well qualification report can be issued to document the fitness for purpose of the given well(s) and define margins against specific acceptance criteria and performance targets.

The key difference between the guidance on re-qualification of wells in ISO 27914 and DNV-RP-J203 is that the ISO 27914 approach focuses on technical specifications and the performance of each specification in fulfilling its functional demand. ISO 27914 addresses the technical challenges that must be addressed in order to re-qualify wells for re-use, which the end-user can refer to. DNV-RP-J203 considers the system as a whole and its application to performing the overall goal of safe, dependable and reliable CO_2 storage, given the threats at hand. DNV-RP-J203 also provides formalized roles and documentation of fit-for-purpose qualification reports for well re-qualification. The approach in DNV-RP-J203 is illustrated in Figure 4-2, showing the steps in the qualification approach. The two provide overlapping strengths in assessing the applicability, useability and overall performance of wells for re-use in CO_2 storage.

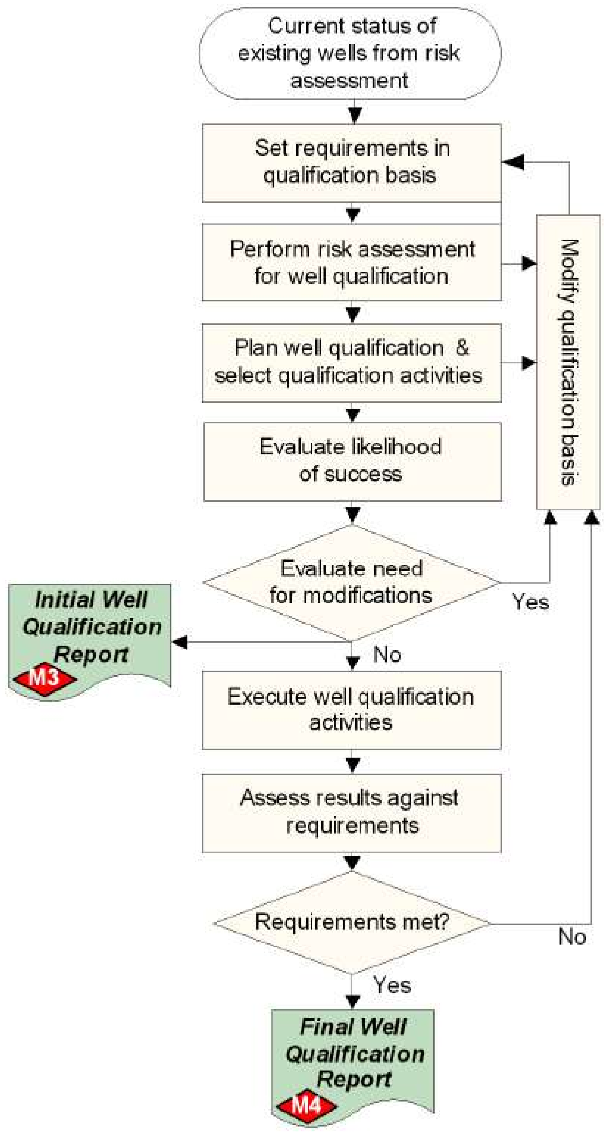


Figure 4-2: Qualification Approach in DNV-RP-J203, based on principles of DNV-RP-A203 (DNV, 2019).

4.2.2 Well re-qualification approaches in real projects

To understand the potential applicability of ISO 27914 and ISO 27916 in re-qualifying wells for CO_2 storage, two industry projects involving re-qualification of wells was performed is presented here. The objective of presenting these cases studies, is to demonstrate important technical considerations when analysing wells for re-qualification, provides an example of well re-qualification in the absence of ISO 27914 and ISO 27916.

Kingsnorth CCS project – Evaluation of wells for re-use

The Kingsnorth CCS project evaluated the potential use of the Hewett field for CO_2 storage. The project also considered the potential for converting and re-qualifying its 28 production wells and the five exploration / appraisal wells (E-On, 2011). The assessment of the Hewett wells identified that the existing wells were not suitable for re-use for CO_2 injection and storage, and that the preferred option would be to drill new wells for the CO_2 injection and storage.

The background for this decision was a high level of uncertainty on the status of the wells and the condition of the well barrier elements. A perceived scarcity of data made assessments difficult and/or inaccurate with an associated risk. The lengthy operational life of the wells contributed to the uncertainty of the suitability of the wells for re-use. This ties in with lifetime assessments of the field and wells, as generally described in NORSOK Y-002 (Standards Norway, 2021b).

No specific reference to which guiding standards or methods for performing the assessment were given in the literature.

Well isolation and integrity evaluation (Europe)

The project evaluated approximately 30 legacy Oil & Gas wells located in a densely populated, sensitive area. The field had historically drilled exploration wells from the 1950's in addition to the production / injection wells drilled and completed in the late 1970's through the 1990's. When performing the well integrity investigations and abandonment activities, surveillance of the wells' leak integrity was non-systematic, i.e. many wells had outstanding wellbore integrity, while other wells had minor leaks and a significant number of wells had substantial well leaks observed. In assessing the well integrity and potential for successful wellbore isolation, the main challenges included:

- Well data quality and data uncertainty
    - There was a significant amount of both historical data and recent data on the well integrity status. Interpretating and categorization the quality of the data and its impact were key aspects.
- Wellbore / geology interactions
    - Proper understanding of the historical well integrity and performance well and its impact on the surrounding geology including overburden geology was paramount in identifying root causes for wellbore isolation problems.
- Risk-based methods for assessing and illustrating well integrity and wellbore isolation
    - Providing illustrations and clear depictions of the underlying threats and proposed solutions for wellbore isolation remediation enabled the stakeholders (project owners, regulators) to understand and accept solutions.

When performing well integrity risk assessment or geological assessment of wells for both hydrocarbon extraction and CO_2 storage, a potential pitfall is to split these tasks up. Splitting up these tasks is also evident in both ISO 27914 and ISO 29716, as the geological assessment is described in Clause 5 (for both ISO 27914 and ISO 27916) and the well assessments are described in Clause 7 (for both ISO 27914 and ISO 27916). The experience gained in the project showed that rather a synergy of the two disciplines provided a major benefit. Historical interactions in the geology and wells' condition, both independent and dependent of each other provided key insight into the differences in the well isolation integrity conditions. Including geology, petrophysics, geoscience, production technology, drilling expertise into the well integrity evaluations through a cross-disciplinary dialogue and workshop approach is extremely useful.

The well integrity evaluations of the legacy wells followed guidance in DNV-RP-E103, "Risk Based Abandonment of Wells." A key tool used this assessment was the Sealing Performance Assessment (SPA). A SPA qualitatively evaluates risk scenarios linked to all well elements (e.g. formation, casing, cement, shoes, packers, etc.) for their capacity to contain pressure and/or flow and the interaction between the wells and the geological formations. The result of a SPA provides a sound basis for determining wellbore isolation (e.g. whether the well will leak CO_2/hydrocarbons) and informing detailed design (e.g. what interventions are required on a risk basis to achieve a high quality well isolation at all levels in a well). An example SPA diagram is shown in Figure 4-3. The SPA provides insight on technical challenges related to the specifications outlined in ISO 27914 and ISO 27916. By following this risk-based approach, the project was successful in isolating the hydrocarbons and providing long-lasting well abandonment solutions.

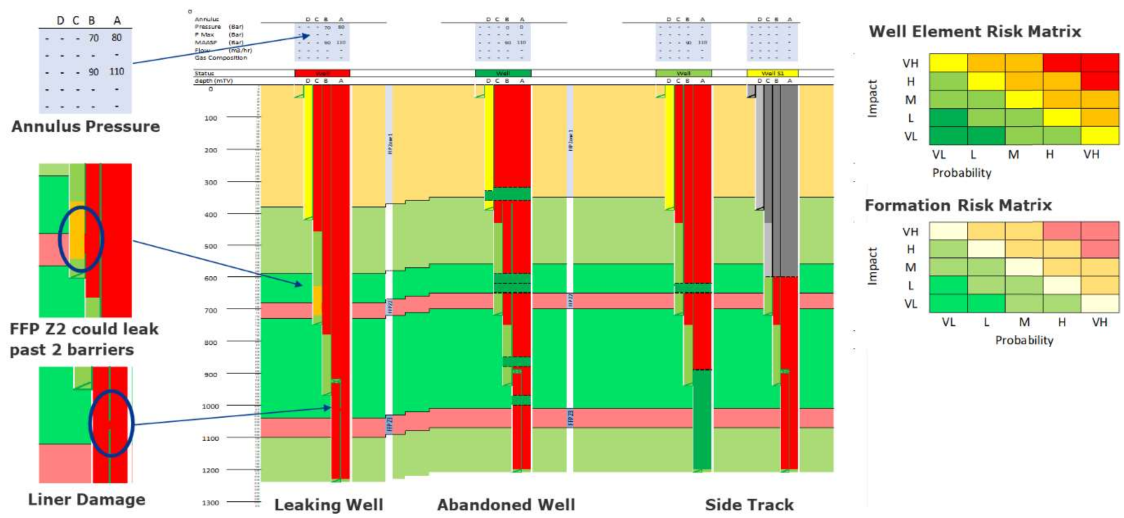


Figure 4-3: SPA diagram showing the risk matrices for well elements and formations, pressure development throughout well life, and identified failure modes on a risk basis, (DNV, 2020).

4.3 Case Study 3 – Development of risk-based M&V program

Regulations give the CO_2 storage project operator considerable freedom when designing a monitoring program to satisfy the overall requirements. The main factors to take into account are which monitoring technologies to use, and the spatial and temporal sampling intervals; factors that influence both cost and information content. This case study elaborates on specific examples in the Quest CCS project Measurement, Monitoring and Verification (MMV) Plan (Shell, 2011) and in the Subpart RR Monitoring, Reporting and Verification (MRV) plan for the Occidental Denver Unit (Occidental, 2015).

4.3.1 Standards and guidelines

There are several standards and guidelines covering monitoring plan details, including ISO 27914, ISO DTR 27923, the US EPA Subpart RR rules, DNV-RP-J203, and the Best Practice Manual published by the National Energy Technology Laboratory: *Best Practices: Monitoring, Verification, and Accounting (MVA) for Geologic Storage Projects* (National Energy Technology Laboratory, 2017). The standards and industry guidelines have similar intentions, to ensure long-lasting integrity of CO_2 injection and storage without leaks or breaches in sealing performance and isolation.

Monitoring practices implemented to meet objectives such as those described in ISO 27914 and ISO 27916 are reflected in the operational examples described in ISO DTR 27923. The US EPA Subpart RR rules provide formal guidance for monitoring CO_2 injection and storage projects and how to achieve regulatory compliance and approval. The DNV-RP-J203 guidance is based on risk management and controlling the defined project risks in achieving CO_2 injection and storage project goals. Table 4-2 indicates how these documents guide the structure of monitoring and verification (M&V) programs. ISO 27916 is not included in this table since it provides very limited guidance on the design of an M&V program. These standards allow alignment with regulatory regimes and local requirements.

Table 4-2: M&V Guidance provided in ISO 27914, USA RR Rules and DNV-RP-J203

<table>
<tr><th>Topic</th><th>ISO 27914</th><th>RR Rules</th><th>DNV-RP-J203</th></tr>
<tr><td>Objective of monitoring plan</td><td>M&V plan to be project specific with site specific considerations to manage health, safety, and environmental risks, and to assess storage performance.</td><td>Provide guidance and requirements for operators when applying for M&V plans and applying for approval.</td><td>Describe the purpose, monitoring targets and performance requirements for monitoring and explain how these will be achieved through the M&V plan.</td></tr>
<tr><td>Pre-injection monitoring</td><td>Determine project vulnerabilities and baseline against which monitoring outputs (and storage performance) are compared</td><td>Establishment of baseline for comparison</td><td rowspan="4">No specific differentiation of monitoring for different operational phases of the project.
Preliminary monitoring plans to be outlined including storage performance forecast.
Monitoring plans to comply with regulatory requirements and to fulfil risk assessment and risk management process.
Screen and select monitoring techniques based on risk management process.
Include contingency plans for monitoring, verification and follow-up.
Relative to closure period monitoring, it is stated that the monitoring plan should demonstrate requirements for site closure.</td></tr>
<tr><td>Injection period monitoring</td><td>- Control HSE risks
- Provide sufficient information on integrity
- Calibrate injectivity performance</td><td>- Monitor performance of CO_2 injection (amounts, quality and location)
- Identify leak potential for injected CO_2 and provide means for quantification of leakage</td></tr>
<tr><td>Closure period monitoring</td><td>Manage leakage risks and demonstrate storage performance to meet site closure criteria</td><td>- Identify potential leakage pathways and means for quantifying leaks of injected CO_2</td></tr>
<tr><td>Post- closure monitoring</td><td>No specific guidance provided.</td><td>No specific guidance provided.</td></tr>
</table>

Similar to Table 4-2, the technical paper by Romanak and Dixon (Romanak & Dixon, 2021) addresses CO_2 storage regulations and to what degree they contain requirements to address different monitoring objectives. A cross evaluation of monitoring objectives and monitoring requirements in regulations and protocols applicable in different areas of the world is described in Table 1 of this paper by Romanak and Dixon.

4.3.2 Monitoring and verification techniques and methods

A wide array of monitoring and verification techniques and methods are available. The methods vary in terms of technological complexity, objectives sought out, information provided, and accuracy of information provided as well as their cost basis. Monitoring, verification and integrity management methods should be identified and implemented for projects based on their specific project requirements and objectives. The following list is a non-exhaustive sample of potential monitoring and verification techniques and methods:

- Subsurface approaches for CO_2 and reservoir monitoring
    - Noble gas tracers
    - Process-based soil gas ratios
    - Carbon isotopes
    - Seismic and microseismic monitoring
    - Density logging
- Well integrity monitoring
    - Topside pressure and temperature monitoring
    - Annulus pressure and temperature monitoring
    - Downhole pressure, temperature monitoring

  - Well maintenance
  - Well interventions checking well barrier elements, for example valve operation and tubing caliper runs or cement bond logs
- Surface equipment monitoring
  - Equipment maintenance
  - Injected CO_2 composition
  - Injected CO_2 rates, volumes and time periods
- Monitoring wells
  - Offset monitoring wells in injected reservoir
  - Offset monitoring wells in groundwater aquifers
- Near wellbore monitoring
  - Groundwater sampling
  - Soil sampling
  - pH monitoring
- Environmental monitoring
  - In-line site CO_2 flux monitoring
  - Remote sensing
  - Chemistry monitoring'
  - Ecosystem studies

4.3.3 Quest CCS Project

The Quest CCS Project has the objective of reducing CO_2 emissions generated by upgrading bitumen from the Alberta oil sands (Shell, 2011). The MMV program was submitted in 2011 to the regulator. Shell performed a gap study to identify the relevant standards available for establishing MMV programs, however international guidance was lacking when the MMV program for Quest was established, as the majority of CCS standards were in their infancy at the time of its release. UK and US regulations and industry knowledge at the time was consulted in addition to Shell's experience in Oil and Gas operations and previous CCS history. Shell had also participated in the CO2QUALSTORE joint industry project, and the guideline developed in this project was used as guidance for the development of the risk assessment approach and monitoring plan[15]. It can also be noted that the CO2QUALSTORE guideline was one of several documents that formed inputs to the development of the bi-national North American standard CSA Z741:12 (CSA, 2018), which in turn was used as a seed document for the development of ISO 27914.

The objectives of the Quest MMV program were (Shell, 2011):

1. Ensure Conformance to indicate the long-term security of CO_2 storage, i.e.
   - Show pressure and CO_2 development inside the storage complex are consistent with models and, if necessary, calibrate and update these models.
   - Evaluate and, if necessary, adapt injection and monitoring to optimize storage performance.
   - Provide the monitoring data necessary to support CO_2 inventory reporting.
2. Ensure Containment to demonstrate the current security of CO_2 storage, i.e.
   - Verify containment, well integrity, and the absence of any environmental effects outside the storage complex.
   - Detect early warning signs of any unexpected loss of containment.

[15] Personal communication.

- If necessary, activate additional safeguards to prevent or remediate any significant environmental impacts as defined by the Environmental Assessment.

The MMV plan delineates the area including the geosphere, hydrosphere, biosphere and atmosphere. The timeline of review relative to the MMV includes the pre-injection, injection, closure, site-closure and post-closure phases.

The process implemented in establishing the Quest MMV plan is shown Figure 4-4. The work processes are set up using a risk-based approach similar to the approach in DNV-RP-J203. The strategy is to identify risks, find mitigation measures to the risks and to re-analyse whether the risks are properly addressed.

In the initial stages of establishing the MMV process, subsurface evaluations, review of historical data and wellbore information and environmental mapping were performed. The focus was on understanding and categorizing containment functionality and risks towards containment of CO_2. The subsurface evaluation identified the initial subsurface safeguards relative to containment. It also evaluated the non-primary subsurface sealing layers, which could provide redundancy and additional safeguard to the CO_2 containment. Additional safeguards in the well integrity of new and legacy wells and normal operating procedures were noted. The totality of the initial risk, safeguard and potential consequence picture was illustrated by performing a bow-tie analysis with the top event being migration of CO_2 and brine from the storage unit out of the storage complex. Consequences considered were hydrocarbon resources impact, groundwater impact, soil impact and CO_2 release to the atmosphere.

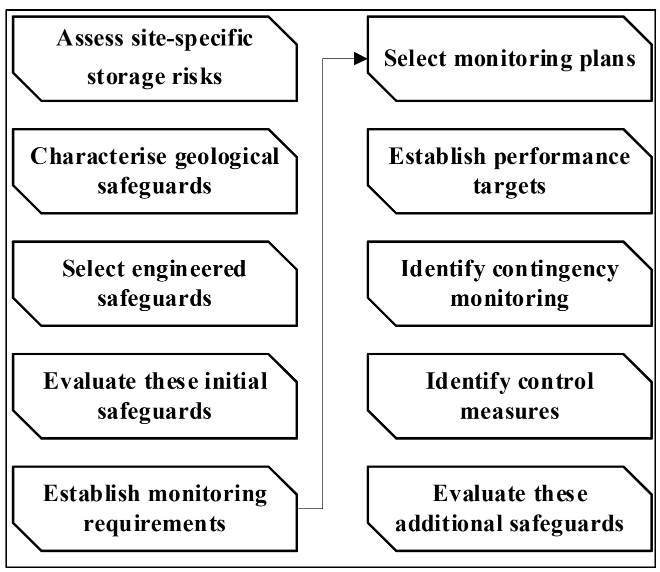


Figure 4-4: Quest MMV establishment procedure, Shell. (2011)

The Quest project performed an in-depth review of the available monitoring technology and evaluated the potential usefulness of the techniques relative to their potential benefits. This process is considered to align with and meet the requirements for the development of the M&V plan in Clause 9.4.2 of ISO 27914. Specific and detailed information on how specified technology is to be implemented for specific purposes is given. For example, corrosion coupons at the injection skid are to be monitored to confirm the dehydration specifications. Another example is that distributed temperature sensing on fibre optics is deployed down to the first barrier on the outside of the intermediate casing providing a continuous means to verify primary well barrier integrity including cement bond integrity.

The overall tasks for the monitoring program are to:

- Monitor CO_2 plume development inside the storage complex

- Monitor pressure development inside the storage complex
- Monitor legacy well integrity
- Monitor injection well integrity
- Monitor geological seal integrity
- Monitor for any hydrosphere impacts
- Monitor for any biosphere impacts
- Monitor for any CO_2 emissions into the atmosphere

These tasks are tied back to an outlined monitoring schedule and overall monitoring plan. The list of specific tasks is more detailed than the guidance provided in ISO 27914, but it can be noted that the list broadly aligns with examples listed in the Note to Clause 9.4.2. The monitoring plan also includes performance targets for the monitoring plan.

4.3.4 Occidental Denver Unit at Wasson Field Project

The Denver Unit CO_2 recovery Plant and CO_2 EOR project in West Texas, operated by Occidental Oil and Gas Corp (Oxy) has been in operation since 2016 with planned operation until 2026 (minimum). The rate of the CCS injection is 1 million tonnes per year and the CO_2 is delivered via pipeline. The CO_2 EOR injection and storage reservoir is at a depth of approximately 1500 meters. The monitoring, reporting and verification (MRV) plan was approved by the US EPA in 2016 (Occidental, 2015).

The MRV plan includes a thorough description of the field's history, production and injection performance, geological characterisation and plan for CO_2 injection as an introduction to the MRV program. The MRV plan is based on the requirements in US EPA's Subpart RR rules. The MRV consists of:

1. **Delineation of the monitoring area and timeframes**
   - **The AMA (active monitoring area)** is defined as the entirety of the Denver Unit
   - **The MMA (maximum monitoring area)** is defined as the Denver Unit with ½ mile buffer zone.
   - **The monitoring timeframe** is from the specified expected beginning of injection period January 1, 2016 to the specified and communicated end date of December 31, 2026. CO_2 injection is expected to continue for roughly five decades after the specified end date.
2. **Evaluation of potential pathways for leakage to the surface, including**
   - **Existing wellbores:** Continuous wellbore monitoring of active injectors and surveillance for CO_2 in production wells, compliance with local and company well integrity requirements and well maintenance.
   - **Faults and fractures:** Subsurface analysis and experience from the basin guided the assessment of the risk relative to faults and fractures.
   - **Natural and induced seismic activity:** Historical seismicity in the basin and potential seismic interaction was studied for the Denver unit.
   - **Previous operations:** Review and analysis of previous records, since the field has had CO_2 injection since the 1980's.
   - **Topside equipment including pipelines:** Common industry best practice, proper maintenance and adherence to company and industry standards were identified as safeguards towards topside CO_2 containment integrity.
   - **Lateral migration outside of the Denver unit:** The lateral migration was included in the subsurface evaluation.
   - **Drilling through the CO_2 area:** The previous experience as well as the regulator interface in the Texas Railroad Commission were identified as mitigation measure relative to the potential for drilling through the CO_2 area.
   - **Diffuse leakage through the cap rock seal:** The diffuse leakage was included in the subsurface evaluation.

3. **Monitoring considerations.** The following aspects are discussed and included in the Oxy plan:
   - CO_2 injection stream composition
   - Flow metering of volume calculation of the CO_2 injection stream, measuring:
     - CO_2 received
     - CO_2 injected into the subsurface
     - CO_2 produced, entrained in the products and CO_2 recycled.
     - CO_2 emitted to surface
   - Leakage monitoring and reservoir monitoring
   - Monitoring of wellbores
4. **Determination of baselines**, to enable observation of differences over time in the subsurface performance relative to CO_2 injection and storage.
5. **Determination of sequestration volumes** using mass balance equations

Oxy also covered topics such as calibration, quality control of measurements, data sampling and analysis and reporting.

4.3.5 Comparison and summary

Standards, guidelines and industry knowledge available show how comprehensive monitoring and verification programs can be established. The combination of requirements from regulations and international standards with a risk-based M&V approach provides a sound basis for CO_2 storage integrity management. ISO 27914 Clause 9 and the examples of monitoring methods and case studies in chapter 10.4 and 10.5 of ISO DTR 27923 provides guidance on planning and implementation of site-specific, risk-based M&V activities for each project phase.

What is missing in industry guidance are both a clear indication on post-site closure monitoring and verification activities, and consistent follow-up regimes. These topics, including post-site closure are generally covered by local regulation and varies between project locations, for example offshore vs. onshore.

The Quest project provided a detailed method for establishing an M&V program. One of the highlights of the Quest M&V plan is that the operator will continuously re-assess and re-analyse the suitability of the M&V program after mitigation measures are implement and project experience is gained. The technology evaluation in the Quest project provides a structured basis for the decision-making process in the M&V plan establishment.

The Oxy project provides clear delineation of the activities for M&V as well as clear objectives on the schedule and timeframe of its validity. This plan includes monitoring of potential leakage pathways and a plan for response and reporting of volumes of CO_2 lost should a loss of containment event occur. This approach is aligned with ISO 27916, for which the key requirement for M&V to support assurance of containment is stated in Clause 6.1.1. e): *The EOR operations management plan (Clause 5.1) shall specify the procedures for […] assessment and management of potential leakage pathway risks and monitoring technologies and procedures (Clause 6.1.3), including definition of detection thresholds for each monitoring method (i.e. meter type, technology, etc.).*

5 CONCEPT FOR USING STANDARDS TO ASSIST IMPLEMENTATION OF CCS PROJECTS IN REGIONS WITHOUT TAILORED CCS REGULATIONS

5.1 Regulatory elements addressed within ISO 27914 and ISO 27916

The Global CCS Institute developed a *CCS Legal and Regulatory Indicator (CCS-LRI)* (GCCSI, 2018) with a broad range of factors that represent critical elements of the regulation of CCS technology. The CCS-LRI relate point scores to 55 countries' legal and regulatory frameworks related to how well they satisfy 5 categories and 29 sub criteria representing the critical elements of a CCS regulation. In order to provide an indication of the comprehensiveness of ISO 27916 and ISO 27914, as well as indicate the areas that a national legislation must cover in addition to the standards, a high-level mapping towards the CCS-LRI 2018 edition is performed and displayed in Table 5-1.

Some key conclusions can be drawn from the high-level mapping shown in Table 5-1:

- The ISO standards provide limited specific support for legal and regulatory elements related to:
    - the CCS approval process,
    - ownership definitions,
    - governmental agencies' roles and responsibility,
    - ownership regime of the sub-surface,
    - transportation of CO_2 (including transboundary movement of CO_2), and
    - dispute resolution mechanisms.
- The ISO standards also support in a general manner the legal and regulatory elements related to
    - definition of the CO_2 stream,
    - identification and accounting for CO_2 leakage,
    - monitoring, storage and siting, closure,
    - reporting and verification,
    - public engagement and
    - risk assessments.

In Table 5-1 each CCS-LRI criterion is marked with either red, yellow, or green colour for which red represents the lowest degree of coverage and green the most comprehensive, though it must be noted that the green areas might still have noncompliance towards some points in the criterion. The CCS-LRI covers the complete CCS chain, from transport to storage. Only the storage part of the CCS chain is relevant for ISO 27916 and ISO 27914.

Table 5-1: Mapping of ISO 27916 and ISO 27914 on CCS Legal and Regulatory Indicator, 2018 edition

<table>
<tr><td colspan="4">Assessment criteria 1) The Clarity and efficiency of the administrative process under the CCS legal framework to apply for, and obtain, regulatory approval for CCS projects</td></tr>
<tr><td>Sub criterion</td><td>Indicators</td><td>Assessment of ISO 27916</td><td>Assessment of ISO 27914</td></tr>
<tr><td>Regulatory roles and responsibilities of government and agencies</td><td>Roles and responsibilities of the respective governments and government agencies are defined at all stages of the CCS project in the legislation and in any accompanying regulations</td><td>Only general mention of “authority responsibility”</td><td>Focus is on the project operator responsibility, not on government agencies.</td></tr>
<tr><td>Approvals process for CCS projects</td><td>Approvals process for CCS projects</td><td>Not part of scope.</td><td>Not part of scope.</td></tr>
<tr><td>Project operator and regulator roles at each CCS project stage</td><td>Distinction between the roles of the project operator and the regulator in the regulatory framework at each stage of the CCS project cycle</td><td>The operator responsibility towards authority mentioned</td><td>Project operator role/responsibility is clearly defined at all storage project stages.</td></tr>
</table>

		throughout. Only storage related.	Authority responsibility is not addressed.
National protocols and guidelines	Assessments and approvals processes consistent with agreed national protocols and guidelines for CCS-specific projects, and other national protocols and guidelines for similar infrastructure / energy projects	Not part of scope.	Not part of scope.
Assessment criteria 2) The Comprehensiveness of the legal framework in providing for all aspects of a CCS project, including siting, design, capture, transport, storage, closure and monitoring for potential releases of stored CO_2			
Sub criterion	**Indicators**	**Assessment of ISO 27916**	**Assessment of ISO 27914**
Integrated manner	CCS-specific legislation, or a number of amendments to existing regulations (e.g. planning or petroleum regulations) Legal and regulatory framework deals with all aspects of CCS in an integrated manner, including all elements of the CCS project cycle Supplements and refers to the development or implementation of existing laws, regulations and / or policies, including with agreed national protocols and guidelines for CCS-specific projects, and other national protocols and guidelines for similar infrastructure / energy projects Clarity of the legal responsibility for CO_2 at different stages of the project cycle Legislation deals with existing users including issues in respect of competing land uses, priorities, incompatibility with other activities, and fee provisions	CCS-specific only for CO_2 storage as part of EOR projects. National legislation must provide definition related to second part of indicator: legal responsibility and existing users.	All stages of the storage project are well defined. National legislation must provide definition related to second part of indicator: legal responsibility and existing users.
Classification of CO_2	Classification of CO_2, including explicit definition of the “CO_2 stream” and instances where CO_2 is exempted or explicitly carved out	Well defined for CO_2-EOR.	Well defined for storage.
Ownership regime for sub-surface storage	Defines ownership of the sub-surface geological surface area, including through a legal regime (either legislative or common law) that provides explicit ownership, including by allocating property interests, tenements and/or rights over the sub-surface area, in respect of the stored CO_2, and the allocation/management of CO_2.	Not part of scope.	Not part of scope.
Design standards for CCS projects	Planning legislation, pollution control laws and occupational health and safety requirements dealing with new plants for CO_2 capture or retrofitting of existing plants Regulatory requirements in respect of design elements such as size and pressure which should be reviewed against latest scientific information and latest building codes Minimum standards for pipeline design through a CCS-specific review process, which includes design standards and requirements for CO_2 pipelines and additional assessments in respect of the composition of CO_2 streams for capture, transport and injection of CO_2	Planning and design elements are not covered.	HSE, planning and design elements for storage are described. Pipeline design is not covered.
Trans-boundary movement of CO_2	Legislation deals with the national (and where applicable, sub-national) transboundary movement of CO_2, during the capture, transportation and storage of CO_2	Not part of scope.	Not part of scope.
Directives and Guidelines	The use of directives and guidelines for CCS-specific projects, and other national protocols and directives and guidelines for similar infrastructure / energy projects	Guideline for CO_2-EOR storage. Its use cannot be accounted for herein.	Guideline for CO_2 storage. Its use cannot be accounted for herein.
Surface access and reclamation	Surface access and reclamation CCS activities regulated on substantially the same basis as other natural resources (such as oil, gas and mining) with monitoring, measurement and verification procedures in place	Monitoring and measurement requirements defined.	Monitoring, measurement and verification requirements defined.
Leakage provisions	Measures for the mitigation, identification and accounting of actual or potential leakages of CO_2, including sanctions or provisions relating to leakage, remediation and/or liability, to	Identification and accounting of leakage is defined.	Identification and measurement of

	be borne by an operator or proponent throughout the operational phase of the project, under law	Liability not covered.	leakage is defined. Liability not covered.
Transportation of CO_2	Transportation provisions in place for the safe transportation of CO_2, and which are consistent with agreed national protocols and guidelines for CCS specific projects, and agreed national protocols and guidelines for similar infrastructure / energy projects Risk management systems in place for transport of CO_2, subject to environmental assessments A regulated pipeline system in place to ensure capture operators have access to storage opportunities and minimise the environmental impact of the pipeline system, including through third party access	Not part of scope.	Not part of scope.
Monitoring and Verification requirements	Monitoring and verification requirements and standards, producing publicly accessible information that can be used to manage the risks of CCS projects	Monitoring and verification requirements defined.	Monitoring and verification requirements defined. Public information partly defined.
Storage and siting	Provisions dealing with investigation, assessment and selection of suitable sites for storage, including storage formation and proponent space requirements Mechanisms for proponents to obtain approval to undertake CCS projects on suitable gas storage sites and for feasibility studies in respect of the injection of CO_2 A tenure regime between proponents and regulators in respect of the injection of CO_2 at specific sites, for CCS activities	Not part of scope as hydrocarbon production is assumed and thus site is already selected. Moreover, selection of sites for CO_2 EOR is driven by commercial considerations for incremental oil production, rather than storage suitability, partly due to proven containment of hydrocarbons offers evidence to support CO_2 containment.	Storage siting is described. Approval mechanisms is not part of scope.
Closure	A closure regime in place that provides for closure period obligations on the project proponent, and addresses liability during the post-closure period (including any possible transfer of responsibility provisions)	Closure regime is described. Post-closure liability is not part of scope.	Closure regime is described. Post-closure liability is not part of scope.
Assessment criteria 3) The extent to which the CCS legal and regulatory framework provides for the appropriate siting of projects and adequate Environmental Impact Assessment (EIA) processes.			
Sub criterion	**Indicators**	**Assessment of ISO 27916**	**Assessment of ISO 27914**
EIA capture / transport	EIAs and approvals processes in place for the capture of CO_2, with mitigation requirements for identified environmental risks and effects EIAs and approvals processes in place for the transport of CO_2, with mitigation requirements for identified environmental risks and effects Legislation imposes an EIA regime that gathers information on the CCS project Terms of reference for EIA are developed with reference to existing legislation and based on established environmental and occupational health and safety requirements A regulated pipeline system in place to ensure capture operators have access to storage opportunities and minimise	Only capture is covered in the context of CO_2-EOR on site.	Not part of scope.

	the environmental impact of the pipeline system, including through third party access		
EIA siting and storage laws	Detailed and transparent assessment of the environmental impact of selecting particular storage sites Regulated storage and injection of CO_2 regime, with processes in place, including multiple schemes, dealing with CO_2 issues in respect of site selection Proper site selection legislation on a site-specific case by case process, with appropriate risk analysis requirements in place	Not covered.	Site selection is described.
Project proponent responsibilities	Responsibility and reporting requirements imposed on the project proponent for evaluating the project's environmental impacts, and providing necessary information to regulators	Quantification of CO_2 loss from EOR is defined. Containment assurance information also must be collected, demonstrated and provided to regulators.	Monitoring of environmental impacts and reporting of compliance is defined.
Government discretion	Government discretion to determine if the proposed CCS activity warrants further environmental assessment due to the potential environmental impacts (even if CCS activities are either on mandatory lists, or carved out by explicit exemptions)	Not part of scope	Not part of scope.
Mitigation and risk management	Requirement to consider appropriate mitigation and remediation scenarios to address potential environmental impacts arising at all phases of the CCS project cycle Set out proposed regime for monitoring, measurement and verification activities, based on consultancy and other experts' reviews of the potential environmental, health and safety impacts Requirement for EIA plans to be submitted when applying for approval to undertake CCS projects	Mitigation, MMV and containment assurance information required to be documented, but approval is not required.	Mitigation, risk management, and MMV information are required to be documented, but approval is not required.
Technical information and technology development	Requirements for projects to demonstrate compliance with approved CCS technology standards Technical and scientific information requirements for all EIAs	Compliance with technical requirements for containment assurance is required, but not full scale EIA.	Compliance with technical requirements for containment assurance is required, but not full scale EIA.
Assessment criteria 4) Stakeholder and public consultation			
Sub criterion	**Indicators**	**Assessment of ISO 27916**	**Assessment of ISO 27914**
Public engagement	Regulatory framework provides for early and long-term public engagement and communication with stakeholders such as landowners, residents, occupants, and municipalities	Not covered.	Public engagement is covered.
Notification requirements	Public engagement and stakeholder notification requirements, articulated through guidelines and / or directives for similar infrastructure / energy projects	Not covered.	Stakeholder and public engagement or communication strategies are defined.
Dispute resolution mechanisms	Dispute resolution mechanisms in place in the event of conflict and / or nonagreement between stakeholders, including recourse to judicial systems	Not covered.	Not covered.
Assessment criteria 5) Liability – closure, monitoring, and accidental releases of stored CO_2			
Sub criterion	**Indicators**	**Assessment of ISO 27916**	**Assessment of ISO 27914**
Closure of CCS project	Regulatory processes in place for project for proponents of CCS sites to follow on completion of the CCS project	Closure process in place but no	Project completion and closure

	A closure regime in place to deal with the closure of sites and for the transfer of long-term liability (only if project proponents have met the regulatory requirements such as monitoring of CO_2), including dealing with post-closure liabilities that might arise or have arisen during the operation of the CCS project Storage liability regimes in place including provisions for long-term liability	transfer of long-term liability.	processes are described. Long-term liability is not covered.
Risk assessment framework	Risk assessment framework in place specifically dealing with closure issues, including a monitoring, measurement and verification process for CCS projects arising on closure	Not covered.	Risk assessment framework is described.
Localised effect liability	In respect of the long-term localised effects and liability arising as a result of CCS projects (including leakages), liability provisions dealing with damage to the environment and human health risks. This includes the availability of corrective and / or remediation measures by the operator and by recourse to existing domestic laws.	Requirements in place to address corrective action for any leaks. Long-term liability is not covered.	Requirements in place to address corrective action for any leaks. Long-term liability is not covered.
Climate change-related liabilities	Measures in place to deal with the long-term climate change related liabilities which arise from CCS projects National climate-change legislation that establishes liability for the release of greenhouse gas into the atmosphere from activities that may include parts of the CCS project cycle, such as under an ETS	Compensation for carbon credits negated by leakage not addressed Long-term liability is not covered.	Compensation for carbon credits negated by leakage not addressed. Long-term liability is not covered.

5.2 Conclusions from regulatory gap analysis in selected countries

Many oil and gas producing countries have technical potential to accommodate CCS projects, but currently lack CCS specific regulations. To provide some practical insight into the applicability of regulatory frameworks in selected countries for deployment of CCS technology, remarks from regulatory gap analysis reports considering Angola, Mozambique, Trinidad and Tobago, Thailand and Indonesia are presented herein. These countries were selected because DNV had either been involved in previous work involving a regulatory maturity assessment for these countries, or there was information available on the state of development of a regulatory framework for CCS in the public domain.

5.2.1 CCS regulatory maturity in Angola

Key conclusions are drawn from the 2013 report: "CCS In Angola - A Gap Analysis", by DNV for the Norwegian Ministry of Petroleum and Energy (DNV, 2013).

Angola is an important oil exporter, one of the largest in Sub-Saharan Africa. The petroleum sector is dominating and has traditionally been the largest source of CO_2 emissions. The country lacks commercial drivers for CCS deployment and enabling policies for environmental technologies such as CCS. Furthermore, storage options in saline formations have not been explored, and the lack of certainty of available storage sites is considered a barrier.

A positive effect of the maturity of the petroleum sector in Angola is a stable petroleum regulatory framework. The existing regulations appear to have most of the appropriate instruments for regulating CO_2 geological storage. This includes provisions for granting of concessions for appraisal and production. Other laws are expected to be essentially suited for regulating the transport of CO_2 and CO_2 capture. Thus, for Angola the most straightforward route to enable CCS appears to be by either amending the existing petroleum law, or by introducing a CCS specific law that builds on the structure and content of the petroleum law. Both approaches would require that additional articles are added for site selection and permitting, monitoring and post-injection site care and long-term liability. Development of a regulatory framework enabling CCS deployment in Angola should still be doable in the short term (< 5 years). These additional issues, except for long term liability, could also be regulated by requiring compliance with relevant parts of international standards such as ISO 27914.

5.2.2 CCS regulatory maturity in Mozambique

Key conclusions are drawn from the 2014 report: "CCS In Mozambique - A Gap Analysis", by DNV for the Norwegian Ministry of Petroleum and Energy (DNV, 2014).

Mozambique is a developing country which only recently started exploiting its offshore gas fields. The technical CCS enabling criteria seems to be promising with good storage potential and reasonable matching of CO_2 sources and storage sites. The capture and transport part of the CCS chain is assessed to be possible to regulate through existing regulations with some modifications, and the storage part by requiring compliance with e.g. ISO 27914. However, there are certain showstoppers identified for CCS to develop in Mozambique. There is a lack of regulatory or commercial incentives that are necessary to make the technology viable. Furthermore, the lack of CCS awareness, skilled personnel, and institutions to carry out projects could be barriers.

While regulations for many of the environmental issues are in place, there are issues that would not be adequately addressed through current Mozambican regulations. Introducing a regulation that would enable CCS would require a significant effort. It is likely that the mining regulation would not be fit for purpose to address all issues regarding site characterization, monitoring, wells, liability etc. associated with CO_2 storage. Hence, it would be recommended to introduce either a new regulation for CO_2 storage, or to make appropriate amendments to the petroleum law. Given the current state of the petroleum law in Mozambique, it is suggested that the latter approach with appropriate amendments should be applied for Mozambique.

5.2.3 CCS regulatory maturity in Trinidad and Tobago

Key conclusions are drawn from the 2012 report: "Carbon Capture and Storage regulatory Review for Trinidad and Tobago", by the Global CCS Institute (GCCSI, 2012).

Trinidad and Tobago is the leading oil and gas producer in the Caribbean and its major sources of CO_2 emissions result from the energy sector, with 55% related to petrochemical processes. The government has looked at CCS as a potential method to reduce the country's greenhouse gas emissions where CO_2 could be captured from industry plants and injected into depleted oil and gas fields or used for enhanced oil recovery.

Due to the legislations that regulates the important and thriving oil and gas sector in Trinidad and Tobago, the country is viewed to be in a good regulatory position for CCS projects to be executed. It is possible to regulate CCS projects there with some modification of the existing regulatory framework or by supplementing with additional CCS legislations. For instance, an amendment to the Pipelines Act 1933 to specifically include CO_2 pipelines would allow the construction and operation of CO_2 pipelines to be accommodated effectively within the existing regulatory framework.

There exist some barriers towards regulating CCS in Trinidad and Tobago. A key barrier is the time it takes for a part of a legislation to complete the governmental and parliamentary process. Furthermore, there is potentially a shortage of people with relevant expertise to legislate a CCS project. Other regulatory gaps identified include:

- The existing legislative framework does not explicitly address liability for stored CO_2 in the event of leakage.
- Exploration and characterisation of a storage site, drilling and injection of CO_2 into a hydrocarbon reservoir would be regulated by the existing oil and gas regulations and license requirements. However, it is not clear whether injection into a saline aquifer which was not located within a petroleum acreage would fall under the regulations.
- There is potential for storage of CO_2 to compete with other subsurface uses, such as hydrocarbon production. The current legislative framework does not provide any guidance on competing rights between different users.

5.2.4 CCS regulatory maturity in Thailand and Indonesia

Key conclusions are drawn from the 2012 report: "Carbon Capture and Storage for Upstream Petroleum Business in Thailand: Governmental Roles and Regulatory Framework, Part 2: Review of Existing Policies, Incentives and Regulatory Frameworks", by the Petroleum Institute of Thailand, DNV and Chandler and Thong-EK (Petroleum Institute of Thailand, DNV and Chandler and Thong-EK, 2012), and the 2013 report "*Prospects for Carbon Capture and Storage in Southeast Asia*", by the Asian Development Bank (ADB, 2013).

Thailand has no law specifically governing CCS, but there are incentives and a regulatory framework in place which can have the potential to be developed into a complete regulatory regime for the CCS chain in Thailand. The most relevant existing regulations are business laws, environmental legislations, and petroleum and mineral legislations. In the petroleum regulations, there are for instance requirements to perform environmental impact assessments, as well procedures for concessions. In 2012, decommissioning rules were drafted but not enacted. Additional relevant regulations are the Hazardous Substance Act, B.E. 2535 (1992) and the Minerals Act, B.E. 2510 (1992). However, none of these are specifically regulating CO_2. There are CO_2 removal plants in place in the country and many industrial and power plants that could serve as CO_2 sources. There is a potential for using depleted oil and gas fields for storage. The initial step for a CCS project of finding a suitable storage site has already started and the next steps would be to develop a regulatory framework for the technology and funding an actual CCS project.

Indonesia has a regulatory regime in place for the oil and gas industry as well as environmental protection laws. The government shows engagement in CCS through contributing to CCS studies. Japan has also introduced a Joint Crediting Mechanism that allows Japanese companies to get carbon credits through implementing CCUS in partner countries, including Indonesia. Both private and public sectors are starting to invest in CCS development and some potential storage sites have been evaluated, though there is limited national funding support. The governmental climate is thus quite mature for the CCS technology, but there is no legal and regulatory framework for CCS projects in place and a regulatory development is needed to further accommodate the technology. The Ministry of Environment would be expected to lead regulatory developments for CCS as it sets standards for the environment and best practice guidelines, whereas the oil and gas regulatory authority also controls gas flow in Indonesia, may regulate CO_2 transport.

Laws and regulations needed to be introduced to implement CO_2 storage or CO_2 EOR in Indonesia and Thailand are described in (ADB, 2013). These laws and regulations include:

- Environmental protection laws and water regulations that include definition of "waste" and "pollution," which could be used to classify CO_2.
- Laws enabling long-term access through ownership, grant, lease, or contract to surface and subsurface rights, including access to pore space for storage.
- Laws governing short-term and long-term liability. This can be addressed by adapting existing liability rules for minerals.
- Clear regulatory and legal framework defining who can build, own, and operate pipelines (or other means) used to transport CO_2 for CCS.
- A clear approach to how CO_2 EOR will be integrated into the production-sharing arrangement and built into oil-gas field development programs.

5.3 Application of ISO 27914 for permitting CO_2 storage projects

There are many similarities between activities related to exploration, development, production and decommissioning of O&G fields, and activities required for exploration, development, operation and closure of CO_2 storage sites. Regulations that have been introduced for governing CO_2 storage activities are therefore often mimicking the petroleum regulations in the region. For instance, while the EU CCS Directive provides requirements the implementation of regulations for CO_2 storage in European countries, it's respective transpositions into national legislation and the set-up of the licensing regime tends to follow the licensing regime for petroleum activities. Similarly, in Australia, the *Offshore Petroleum and Greenhouse Gas Storage Act 2006* (Australian Government), is set up to provide an effective regulatory framework for both (a) *petroleum exploration and recovery*; and (b) *the injection and storage of greenhouse gas substances*; in offshore areas.

The similarity between licensing regimes for O&G developments and CO_2 storage projects also suggest that the existing petroleum licensing regime, complemented by standards setting specific requirements for CO_2 storage projects that are not adequately reflected in the petroleum regulations, may combined form a licensing regime for CO_2 storage projects.

It is our understanding that the State of South Australia is following this route to develop a regulatory framework. This framework will apply, for instance, to the licensing process for the Santos Cooper Basin CCS project intending to store 1.7 million tonnes CO_2 per year into the depleted fields of the Cooper Basin. A brochure from the Government of South Australia providing information on CCS to the public makes specific reference to the reliance on the standards (Government of South Australia, Department of Energy and Mining, 2020).

> *The significance of the ISO/TC 265 work [which includes ISO 27914 and ISO 27916] to Australia is that regulation of CCS, capture, transport and storage activities is administered under the various state and Commonwealth Acts – e.g. the South Australian Petroleum and Geothermal and Energy Act 2000 and the Commonwealth Offshore Petroleum and Greenhouse Gas Storage Act 2006. These Acts, as is the case across all of Australia, are risk-based legislation which call upon recognised good industry practice. The ISO standards will augment these legislative requirements for CCS regulated activities.*

The intent of this section is to outline how ISO 27914 can be used alongside petroleum regulations to form a licensing regime for CO_2 storage[16]. We show first, in Figure 5-1, how requirements in ISO 27914 clauses align with the typical requirements for passing key project milestones in a CO_2 storage project, from site selection through to site closure and transfer of responsibility to a post-closure steward, where a mechanism for this is in place.

Next, we provide an example where we illustrate (in Figure 5-2 and Figure 5-3) how certification of conformity with ISO 27914 at milestones 2 to 5 and 7 in Figure 5-1 can be used as a supplement to the existing approval processes in the Norwegian petroleum regulations to establish a tenure process with requirements that are largely equivalent to the requirements for the associated licenses in the CO_2 storage regulations.

[16] ISO 27916 can also be used to guide implementation of CO_2 EOR projects within the O&G regulatory framework, e.g. regarding aspects of well construction and demonstration of containment assurance. However, ISO 27916 is not very well suited to guide permitting steps for a CO_2 EOR project, as that would generally be covered by the existing petroleum regulation. Further, as ISO 27916 is primarily focussed on accounting aspects, the view of the authors is that ISO 27916 would principally be applied to support how GHG emission reductions associated with CO_2 EOR may be incorporated in GHG reporting.

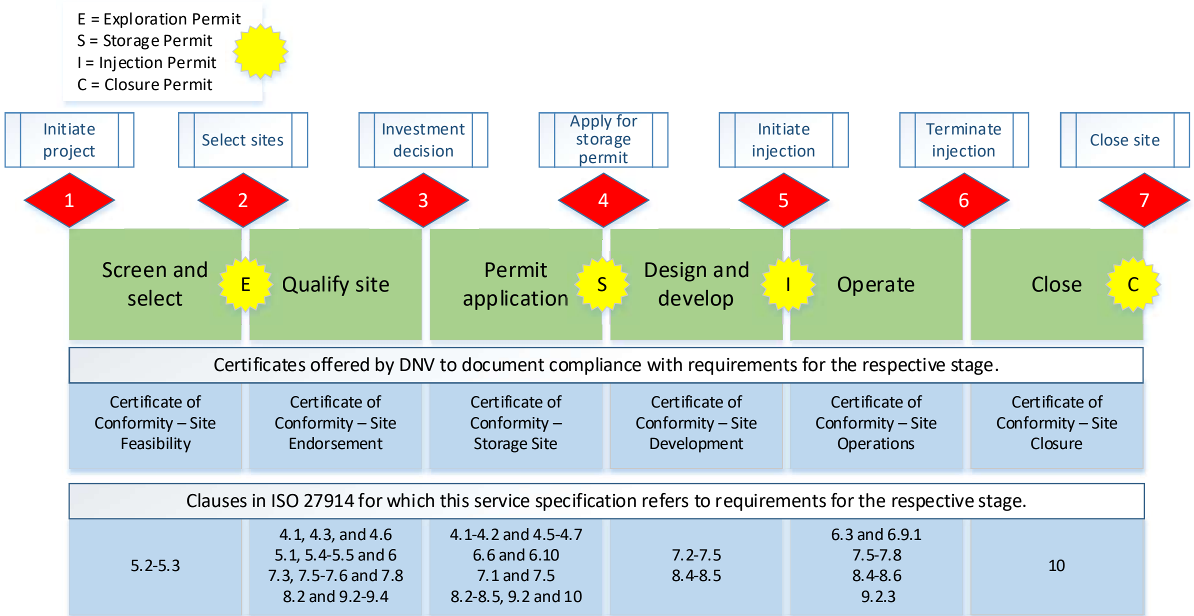


Figure 5-1: Certificates defined in DNV-SE-0473 for conformity with ISO 27914 at different stages in the life-cycle of a CO_2 storage project, and the key clauses that contain requirements for the corresponding stage.

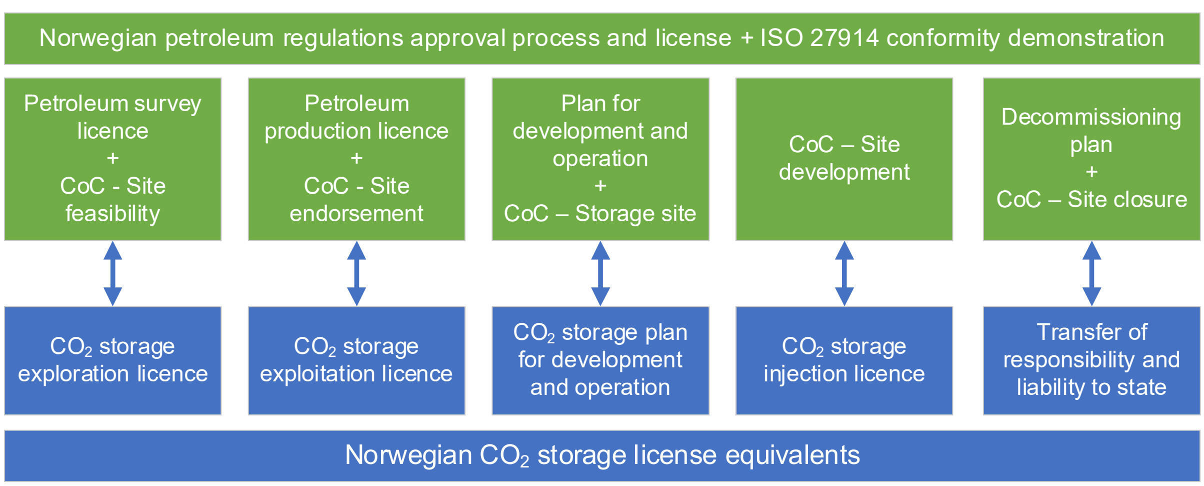


Figure 5-2: Illustration of how process for approvals under the Norwegian petroleum regulations can be combined with certification of conformity (CoC) with ISO 27914 to form a path to meet requirements for CO_2 storage licences for the equivalent stages in the project development life-cycle.

The example shown in Figure 5-2 and Figure 5-3 is specific to the Norwegian regulatory framework. However, the general tenure process and licensing regime in the other petroleum producing jurisdictions that have introduced CO_2 storage specific regulations are similar. We therefore believe that:

i) analogous versions of Figure 5-2 can also be developed for these other jurisdictions, with linkage to the corresponding permits and licenses shown in Table 5-2; and

ii) the coupling of the licensing regime in existing petroleum regulations with relevant technical requirements in ISO 27914 can form a conceptual licensing framework for CO_2 storage in jurisdictions with existing petroleum regulations.

This suggests that a conceptual tenure regulation can be developed through the use of a petroleum licensing regime, where the licenses and approvals for O&G exploration, development, production and decommissioning are adapted to also apply to CO_2 storage projects at the corresponding stage of development.

Table 5-2: Examples of corresponding permits and approvals for CO_2 storage in selected jurisdictions.

Life-cycle stage (Figure 5-1)	CO_2 storage regulations			
	Norway	**Australia**	**Alberta**	**USA**
Site selection	Exploration license	GHG Assessment permit	Evaluation permit	N/A
Site qualification	Exploitation license	Declaration of identified storage formation	Carbon sequestration lease	Class VI permit
Storage site	Approved Plan for Development and Operation	Approved site plan	Approved MMV and closure plans	Various plan approvals
Site development	Injection license	Injection license	Well approvals	Authorization to inject
Site closure	Transfer of responsibility	Transfer of responsibility	Closure certificate / Transfer of responsibility	Site closure authorization[17]

[17] US rules do not provide for transfer, but some individual states do provide for transfer – e.g., Louisiana, Nebraska, and North Dakota.

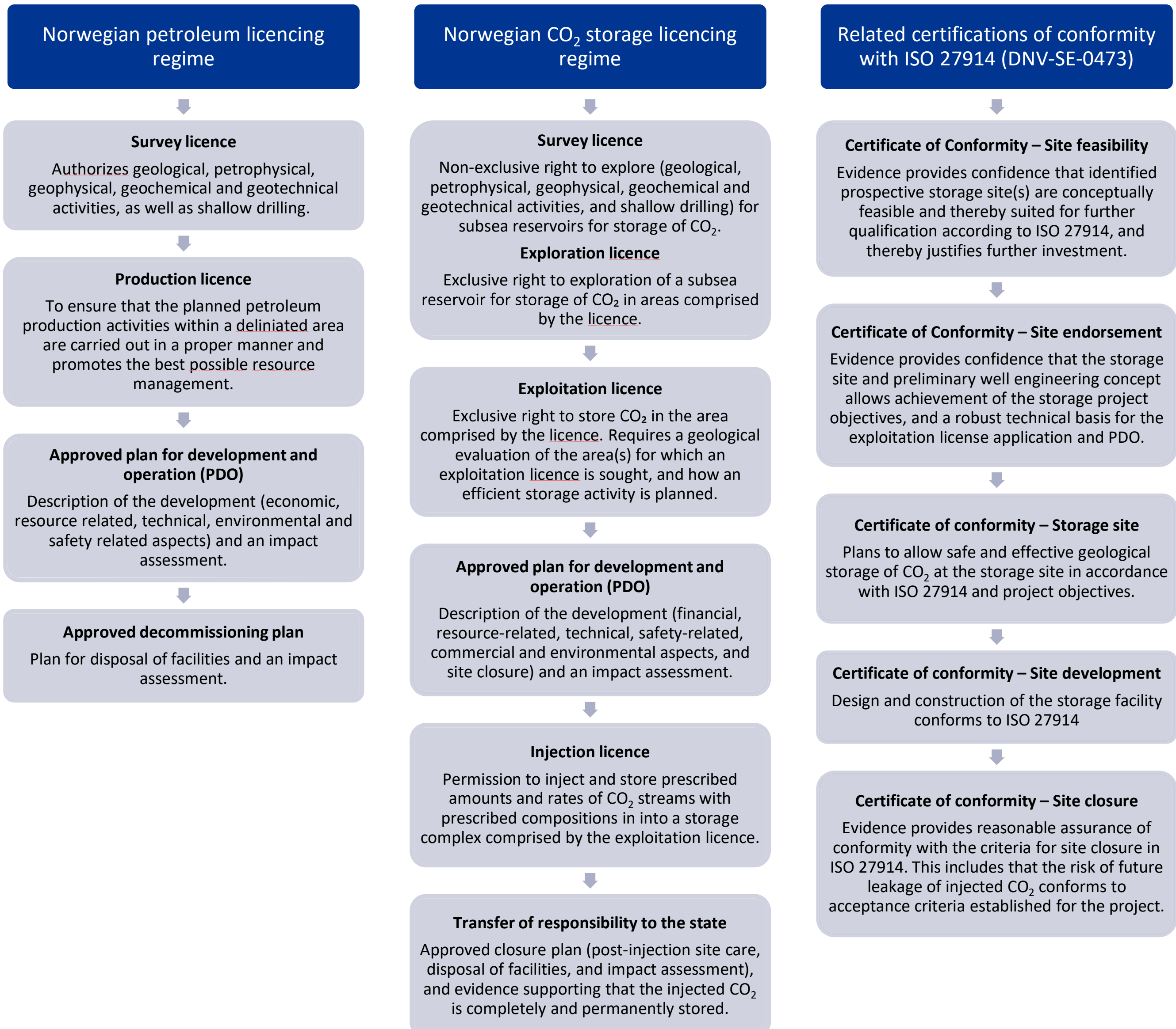


Figure 5-3: Relevant licences and associated requirements and permissions in the Norwegian petroleum regulations and regulations for subsea geological storage of CO_2 on the Norwegian Continental Shelf (NCS).

6 SUMMARY

In this report, we first summarised, compared, and contrasted the ISO 27914 and ISO 27916 relating to the geological storage of carbon dioxide with current regulatory frameworks and provided a high-level understanding of the content of the standards. We then further evaluated the potential use of two ISO standards as supplement to existing regulations. This was done in a generic sense in Section 3 examining potential application to support storage site permitting, application approval and evaluation of closure requirements. This evaluation was then complemented by three case-studies in Section 4 analysing in further detail how ISO 27914 and ISO 27916 can be applied to guide processes for site feasibility evaluations, well re-qualification for CO_2 storage and development of monitoring and verification programs. Finally, in Section 5, we mapped the breadth of coverage of ISO 27914 and ISO 27916 relative to various regulatory elements and introduced a concept for using ISO 27914 to assist implementation of CO_2 storage projects in countries lacking mature CCS regulations.

Key takeaways from the study include:

1. ISO 27914 and ISO 27916 are very much complementary, with minimal overlap. A key reason for this was desired by key stakeholders to have a clear separation between the two standards, so that ISO 27914 would apply only to CO_2 storage projects and ISO 27916 would apply only to CO_2 EOR projects.

2. The two standards are designed to serve quite different purposes. The objective of ISO 27914 is to promote commercial, safe, long-term containment of carbon dioxide in geological systems in a way that minimizes risk to the environment, natural resources, and human health. The objective of ISO 27916 is to promote the use of geologic storage associated with CO_2-EOR by providing a common process for assuring safe, long-term containment and for quantifying and documenting the amount of CO_2 that is stored in association with CO_2 EOR.

3. ISO 27914 and ISO 27916 together with other industry guidelines can support CCS project development and permitting and approval.

4. Case studies show that ISO 27914 and ISO 27916 can be used to guide processes for evaluating technical challenges on three key topics in alignment with industry best practice knowledge. These topics are:

    - Determining site feasibility for CO_2 storage
    - Re-qualification of wells at CO_2 storage sites
    - Development of risk-based M&V program

5. There are many similarities between activities related to exploration, development, production and decommissioning of oil and gas (O&G) fields, and activities required for exploration, development, operation and closure of CO_2 storage sites. Regulations that have been introduced for governing CO_2 storage activities are therefore often mimicking the petroleum regulations in the region. The similarities between licensing regimes for O&G developments and CO_2 storage projects also suggest that the existing petroleum licensing regime, complemented by standards setting specific requirements for CO_2 storage projects that are not adequately reflected in the petroleum regulations, may be combined to contribute to the development of a licensing regime for CO_2 storage projects. Areas within regulations for CO_2 storage and CO_2 EOR that are not covered by ISO 27914 and ISO 27916 include the management of long-term liability and regulatory approval processes.

7 REFERENCES

ADB. (2013, September). *Prospects for Carbon Capture and Storage in Southeast Asia.* Retrieved from https://www.adb.org/sites/default/files/publication/31122/carbon-capture-storage-southeast-asia.pdf

Alberta Government. (2010). *Bill 24 - Carbon Capture and Storage Statues Amendment Act.* Retrieved from https://docs.assembly.ab.ca/LADDAR_files/docs/bills/bill/legislature_27/session_3/20100204_bill-024.pdf

Alberta Government. (2011). *Carbon Sequestration Tenure Regulation.* Retrieved from https://open.alberta.ca/publications/2011_068

Alberta Government. (2013). *Carbon capture & storage : summary report of the regulatory framework assessment.* Retrieved from https://open.alberta.ca/dataset/9781460105641

Alberta Government. (2015, June 23). *Quantification protocol for CO2 capture and permanent storage in deep saline aquifers.* Retrieved from https://open.alberta.ca/publications/9780778572213

API. (2006). *API RP 90 : Annular Casing Pressure Management for Offshore Wells.* Retrieved from https://global.ihs.com/doc_detail.cfm?document_name=API%20RP%2090&item_s_key=00483765

API. (2008). *API TR 10TR1 : Cement Sheath Evaluation.* Retrieved from https://global.ihs.com/doc_detail.cfm?document_name=API%20TR%2010TR1&item_s_key=00237621

API. (2010, May). *API RP 65-2 : Isolating Potential Flow Zones During Well Construction.* Retrieved from https://global.ihs.com/doc_detail.cfm?document_name=API%20RP%2065%2D2&item_s_key=00551568

Australian Government. (n.d.). *Regulating offshore greenhouse gas storage in Australian Commonwealth waters.* Retrieved from Accessed September 15th 2021: https://www.industry.gov.au/regulations-and-standards/regulating-offshore-greenhouse-gas-storage-in-australian-commonwealth-waters

C2ES. (2012, February). *Greenhouse Gas Accounting Framework for Carbon Capture and Storage Projects.* Retrieved from https://www.c2es.org/document/greenhouse-gas-accounting-framework-for-carbon-capture-and-storage-projects/

California Air Resources Board. (2018, August 13). *Carbon Capture and Sequestration Protocol Under the Low Carbon Fuel Standard.* Retrieved from https://ww2.arb.ca.gov/resources/documents/carbon-capture-and-sequestration-protocol-under-low-carbon-fuel-standard

CSA. (2018). *CSA Z741-12 Geological storage of carbon dioxide.* Retrieved from https://www.csagroup.org/store/product/2421962/

DNV. (2010, January 29). *CO2QUALSTORE Report - Guideline for Selection, Characterization and Qualification of Sites and Projects for Geological Storage of CO2. Report No.: 2009-1425.*

DNV. (2012, June). *Qualification Management for Geological Storage of CO2.* Retrieved from https://rules.dnv.com/docs/pdf/dnvpm/codes/docs/2013-07/Dss-402.pdf

DNV. (2013). *CCS in Angola - A Gap Analysis, DNV Report No. 16862IB-6/0.*

DNV. (2014). *CCS in Mozambique - A Gap Analysis, DNV Report No. 16862IB-5/0.*

DNV. (2017a, October). *DNV-SE-0473: Certification of sites and projects for geological storage of carbon dioxide.* Retrieved from https://www.dnv.com/oilgas/download/dnv-se-0473-certification-of-sites-and-projects-for-geological-storage-of-carbon-dioxide.html

DNV. (2017b). *DNV-RP-J203 Geological storage of carbon dioxide.* Retrieved from https://oilgas.standards.dnvgl.com/download/dnv-rp-j203-geological-storage-of-carbon-dioxide

DNV. (2019, September). *DNV-RP-A203 Technology qualification.* Retrieved from https://oilgas.standards.dnvgl.com/download/dnv-rp-a203-technology-qualification

DNV. (2020, September). *DNV-RP-E103 Risk-based abandonment of wells.* Retrieved from https://oilgas.standards.dnvgl.com/download/dnv-rp-e103-risk-based-abandonment-of-wells

DNV GL. (2014). *Post-Closure Stewardship Fund Methodology, Final report.*

Environment and Climate Change Canada. (2020). *Clean fuel regulations : quantification method for CO2 capture and permanent storage.* Retrieved from https://publications.gc.ca/site/eng/9.893172/publication.html

E-On. (2011, February). *Kingsnorth CCS Demonstration Project - Key Knowledge Reference Book .* Retrieved from https://ukccsrc.ac.uk/sites/default/files/documents/content_page/EON_FEED_key-knowledge-reference-book.pdf

European Commission. (2009, April 23). *DIRECTIVE 2009/31/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL.* Retrieved from https://ec.europa.eu/clima/policies/innovation-fund/ccs/directive_en

European Commission. (2010, June 8). *2010/345/EU: amending Decision 2007/589/EC as regards the inclusion of monitoring and reporting guidelines for greenhouse gas emissions from the capture, transport and geological storage of carbon dioxide.* Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32010D0345&from=EN

European Commission. (2021, June 4). *Annex 1 of delegated regulation under Act 2800/3 .* Retrieved from Chapter 5.12. Underground permanent geological storage of CO2: https://ec.europa.eu/finance/docs/level-2-measures/taxonomy-regulation-delegated-act-2021-2800-annex-1_en.pdf

GCCSI. (2012, October). *Carbon Capture and Storage Regulatory Review for Trinidad and Tobago.* Retrieved from https://www.globalccsinstitute.com/archive/hub/publications/54126/ccs-regulatory-review-trinidad-tobago.pdf

GCCSI. (2018, October 16). *Legal & Regulatory Indicator (CCS-LRI).* Retrieved from https://www.globalccsinstitute.com/resources/publications-reports-research/legal-regulatory-indicator-ccs-lri/

Government of South Australia, Department of Energy and Mining. (2020). *Carbon capture and Storage.* Retrieved from https://sarigbasis.pir.sa.gov.au/WebtopEw/ws/samref/sarig1/image/DDD/BROCH123.pdf

IPCC. (2006). *2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 2: Energy*. Retrieved from Chapter 5: Carbon dioxide transport, injection and geological storage: https://www.ipcc-nggip.iges.or.jp/public/2006gl/vol2.html

ISO. (2017a). *ISO 27914:2017, Carbon dioxide capture, transportation and geological storage — Geological storage.* Retrieved from https://www.iso.org/standard/64148.html

ISO. (2017b). *ISO 16530-1:2017 Petroleum and natural gas industries — Well integrity — Part 1: Life cycle governance.* Retrieved from https://www.iso.org/standard/63192.html

ISO. (2019). *ISO 27916:2019, Carbon dioxide capture, transportation and geological storage — Carbon dioxide storage using enhanced oil recovery (CO2-EOR).* Retrieved from https://www.iso.org/standard/65937.html

ISO. (2021). *ISO/PRF TR 27923 Carbon Dioxide Capture, Transportation and Geologic Storage - Injection Operations, Infrastructure and Monitoring.* Retrieved from https://www.iso.org/standard/67275.html?browse=tc

National Energy Technology Laboratory. (2017). *Best Practices: Monitoring, Verification, and Accounting (MVA) for Geologic Storage Projects, 2017 Revised Edition.* Retrieved from https://www.netl.doe.gov/sites/default/files/2018-10/BPM-MVA-2012.pdf

NOGEPA. (2018a). *Standard 45 – Well Decommissioning/Het buiten gebruikstellen van putten.* Retrieved from https://www.nogepa.nl/download/standard-45-well-decommissioning/?lang=en

NOGEPA. (2018b). *Standard 51 – Operational Barriers for Well Integrity.* Retrieved from https://www.nogepa.nl/download/standard-51-operational-barriers-for-well-integrity/?lang=en

Norsk olje&gass. (2013). *117 Recommended guidelines for Well Integrity.* Retrieved from https://www.norskoljeoggass.no/en/working-conditions/retningslinjer/drilling/117-recommended-guidelines-for-well-integrity-/

NORSOK. (n.d.). *NORSOK Standard D-010.* Retrieved from Well integrity in drilling and well operations: https://www.standard.no/en/webshop/ProductCatalog/ProductPresentation/?ProductID=1330906

Norwegian Ministry of Climate and Environment. (n.d.). *Forskrift om begrensning av forurensning (forurensningsforskriften).* Retrieved from https://lovdata.no/dokument/SF/forskrift/2004-06-01-931

Norwegian Petroleum Directorate. (2014, December 5). *Regulations relating to exploitation of subsea reservoirs on the continental shelf for storage of CO_2 and relating to transportation of CO_2 on the continental shelf.* Retrieved from https://www.npd.no/en/regulations/regulations/exploitation-of-subsea-reservoirs-on-the-continental-shelf-for-storage-of-and-transportation-of-co/

Occidental. (2015, December). *Oxy Denver Unit CO2 Subpart RR Monitoring, Reporting and Verification (MRV) Plan.* Retrieved from https://www.epa.gov/sites/default/files/2015-12/documents/denver_unit_mrv_plan.pdf

Oil and Gas UK. (2015). *Guidelines on Qualification of Materials for the Abandonment of Wells – Issue 2.* Retrieved from https://oguk.org.uk/product/guidelines-on-qualification-of-materials-for-the-abandonment-of-wells-issue-2/

Petroleum Institute of Thailand, DNV and Chandler and Thong-EK. (2012). *Carbon Capture and Storage for Upstream Petroleum Business in Thailand: Governmental Roles and Regulatory Framework, Part 2: Review of Existing Policies, Incentives and Regulatory Frameworks.*

Petroleum Safety Authority Norway. (2020a, February 25). *Regulations Relating to Safety and Working Environment for Transport and Injection of CO2 on the Continental Shelf (CO2 Safety Regulations).* Retrieved from https://www.ptil.no/contentassets/91050f289295418d806f84a6dc39a4c5/co2-sikkerhetsforskriften_e.pdf

Petroleum Safety Authority Norway. (2020b, February 25). *Guidelines regarding the CO2 safety regulations.* Retrieved from https://www.ptil.no/contentassets/40e3bb35dfe144529aa9a0eb636203ee/guidelines-co2-safety-regulations.pdf

REX-CO2. (2020, February 28). *Deliverable D2.1: Current state-of-the-art assessments and technical approach for assessment of well re-use potential and CO2/brine leakage risk.* Retrieved from https://rex-co2.eu/downloads.html

Romanak, K., & Dixon, T. (2021). Technical monitoring considerations for advancing CCS projects under the California Low Carbon Fuel Standard in relation to other global regulatory regimes. *International Journal of Greenhouse Gas Control (2021) [Article in Press]* .

Shell. (2011). *Quest CCS Project Measurement, Monitoring and Verification Plan.* Retrieved from https://open.alberta.ca/dataset/46ddba1a-7b86-4d7c-b8b6-8fe33a60fada/resource/00910deb-ff9a-4b11-8282-bce28bc2e2f2/download/measurementmonitoringandverificationplan.pdf

Standards Norway. (2021a). *NORSOK D-010:2021 Well integrity in drilling and well operations.* Retrieved from https://www.standard.no/en/webshop/ProductCatalog/ProductPresentation/?ProductID=1330906

Standards Norway. (2021b). *NORSOK Y-002:2021 Life extension for transportation systems.* Retrieved from https://www.standard.no/no/Nettbutikk/produktkatalogen/Produktpresentasjon/?ProductID=1360102

U.S. EPA. (2010, December 10). *Class VI - Wells used for Geologic Sequestration of CO2.* Retrieved from https://www.epa.gov/uic/class-vi-wells-used-geologic-sequestration-co2

U.S. EPA. (2016, September 12). *Subpart RR – Geologic Sequestration of Carbon Dioxide.* Retrieved from https://www.epa.gov/ghgreporting/subpart-rr-geologic-sequestration-carbon-dioxide

U.S. EPA. (n.d.). *Class II Oil and Gas Related Injection Wells.* Retrieved from https://www.epa.gov/uic/class-ii-oil-and-gas-related-injection-wells

US Department of Treasury, Internal Revenue Service. (2021, January 6). *Credit for Carbon Oxide Sequestration.* Retrieved from https://www.irs.gov/pub/irs-drop/td-9944.pdf

About DNV

DNV is the independent expert in risk management and assurance, operating in more than 100 countries. Through its broad experience and deep expertise DNV advances safety and sustainable performance, sets industry benchmarks, and inspires and invents solutions.

Whether assessing a new ship design, optimizing the performance of a wind farm, analyzing sensor data from a gas pipeline or certifying a food company's supply chain, DNV enables its customers and their stakeholders to make critical decisions with confidence.

Driven by its purpose, to safeguard life, property, and the environment, DNV helps tackle the challenges and global transformations facing its customers and the world today and is a trusted voice for many of the world's most successful and forward-thinking companies.

Evaluating technology options to mitigate greenhouse gas emissions

IEA Greenhouse Gas R&D Programme

Pure Offices, Cheltenham Office Park, Hatherley Lane,
Cheltenham, Glos. GL51 6SH, UK

Tel: +44 1242 802911

mail@ieaghg.org
www.ieaghg.org