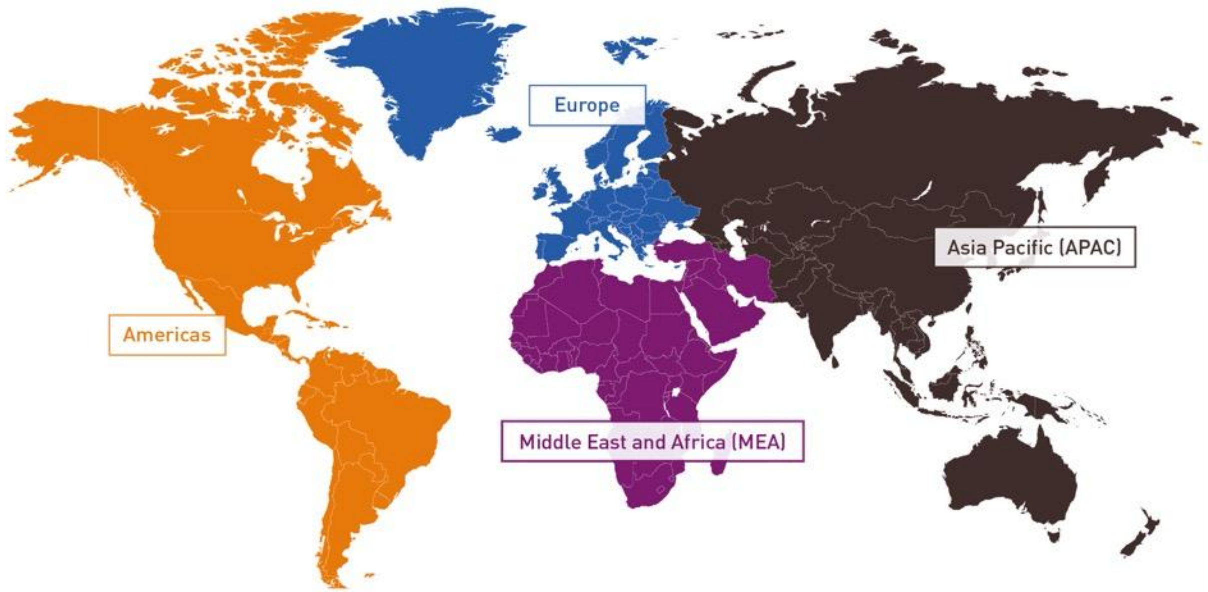
Well abandonment and integrity evaluation for CO_2 storage

We speak on behalf of a global membership

IOGP has 93 Members (as of February 2025)



The map shows the division of the world into four regions on which subscription shares are based.
The delineation of zones is not intended to reflect offshore boundaries.

Map shows locations of Member Head Offices. Many operate globally

Americas

APA Corporation
API
Arpel
Atlantic LNG
Baker Hughes
CAPP
Cenovus Energy
Chevron
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IADC
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Middle East and Africa (MEA)

Addax Cameroon
ADNOC
Aramco
Azule Energy
Bapco Energies
Basrah Gas Company
CCED
Crescent Petroleum
Dana Gas
Dolphin Energy
Dragon Oil (ENOC)
EGPC
Gulf Keystone Petroleum
KOC
North Oil Company
PDO
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Europe

Aker BP
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DNV
Element NL
Energy Institute
Eni SpA
Equinor
Galp
Harbour Energy
HeliOffshore
Ipieca
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MOL
Offshore Energies UK
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OMV
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ONGC
PETRONAS Carigali
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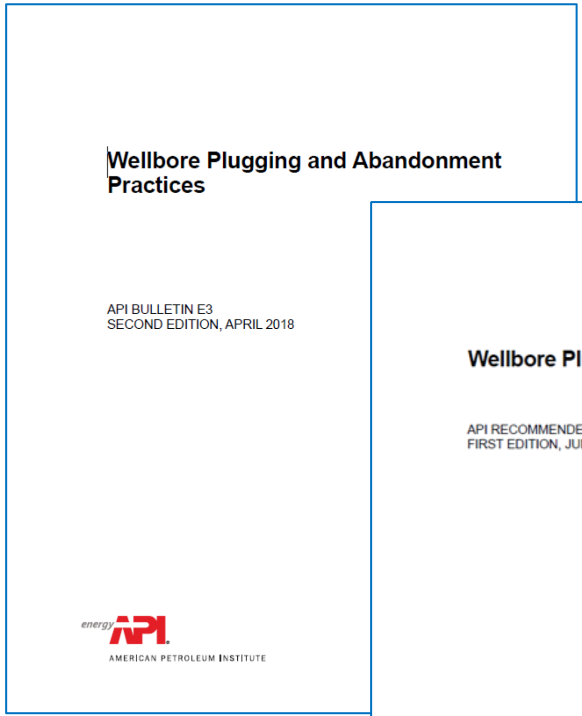
PTTEP
Reliance
SOCAR
Woodside Energy

International Association of Oil & Gas Producers

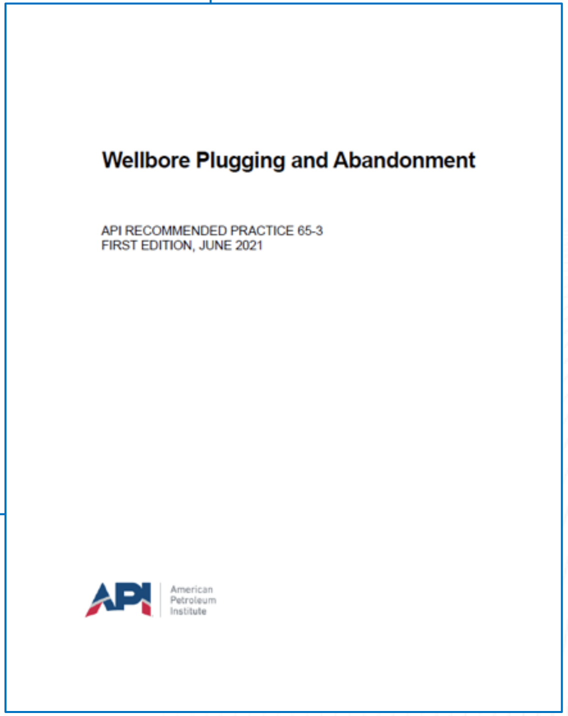
Industry Standards and Guidelines on the Topic



Wellbore Plugging and Abandonment Practices

API BULLETIN E3
SECOND EDITION, APRIL 2018

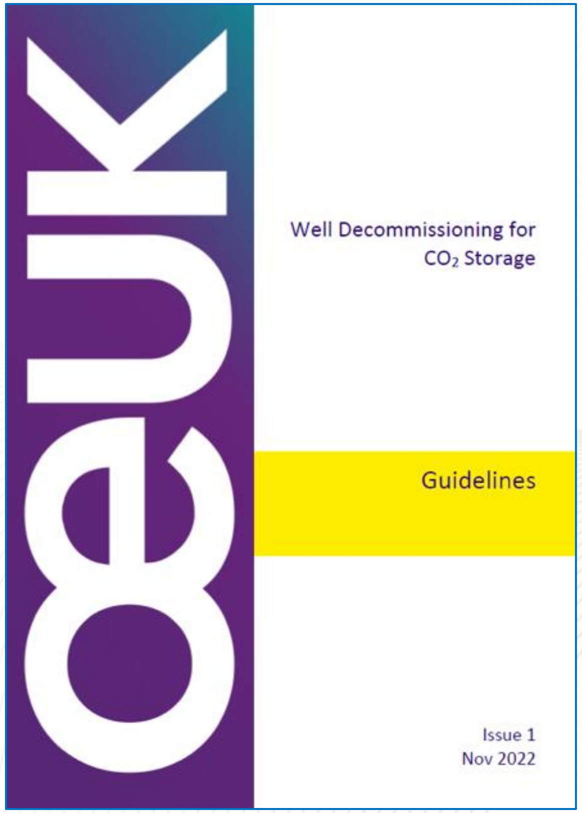
energy API
AMERICAN PETROLEUM INSTITUTE



Wellbore Plugging and Abandonment

API RECOMMENDED PRACTICE 65-3
FIRST EDITION, JUNE 2021

API American Petroleum Institute

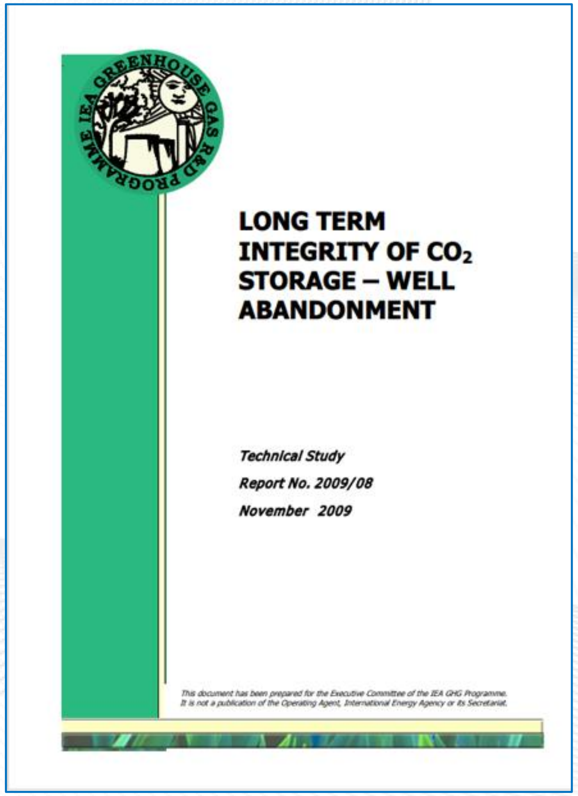


OEUK

Well Decommissioning for CO_2 Storage

Guidelines

Issue 1
Nov 2022



IEA GREENHOUSE GAS R&D PROGRAMME

LONG TERM INTEGRITY OF CO_2 STORAGE – WELL ABANDONMENT

Technical Study
Report No. 2009/08
November 2009

This document has been prepared for the Executive Committee of the IEA GHG Programme. It is not a publication of the Operating Agent, International Energy Agency or its Secretariat.

Work Scope and Boundaries

Scope is abandoned well leak risk:

- Educate reader on storage project realities (pressure limits) and differences to Oil and Gas
- Barrier philosophy and leak rate
- Legacy wells – screening and risking
- Project wells – timing and issues with P&A
- Barrier degradation consequences

Scope does <u>not</u> include:

- Leakage due to geologic factors (faults, seismicity)
- Storage project measuring, monitoring, and validation (MMV) commitments
- Barrier placement operations

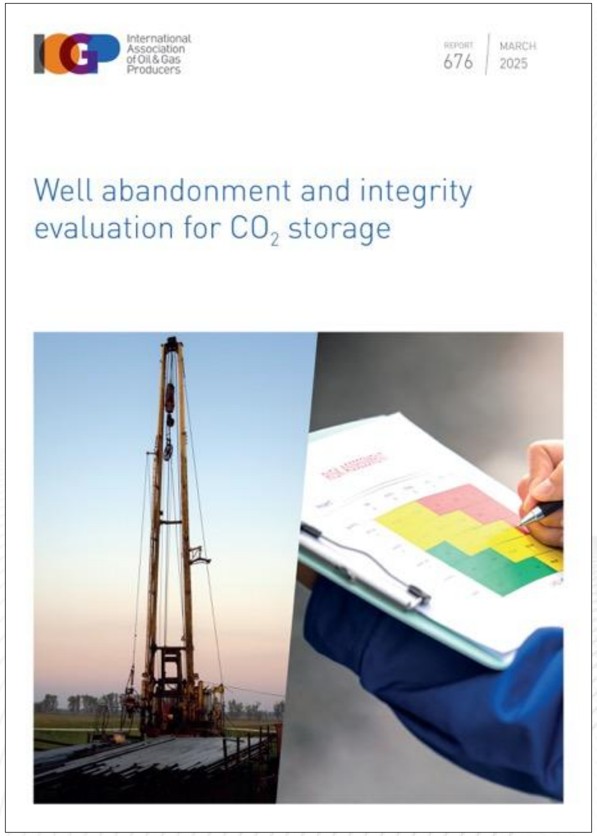
IOGP Report 676 - Overview

IOGP Report 676 is written as guidance, not a specification or requirement

This document provides guidelines and considerations for well plugging and abandonment (P&A) approaches for both project and legacy wells within a carbon dioxide (CO_2) geologic storage site.

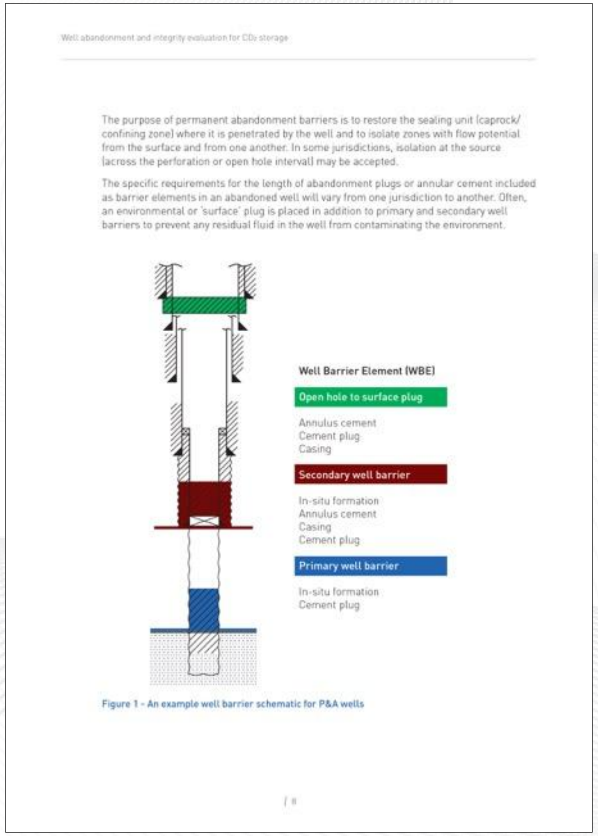
Main Content Sections

- Principles of well plugging and abandonment
- Plugging and abandonment for Project wells
- Plugging and Abandonment for Legacy Wells
- Appendix – Well types and Conditions


International Association of Oil & Gas Producers

REPORT 676 | MARCH 2025

Well abandonment and integrity evaluation for CO_2 storage


Well abandonment and integrity evaluation for CO_2 storage

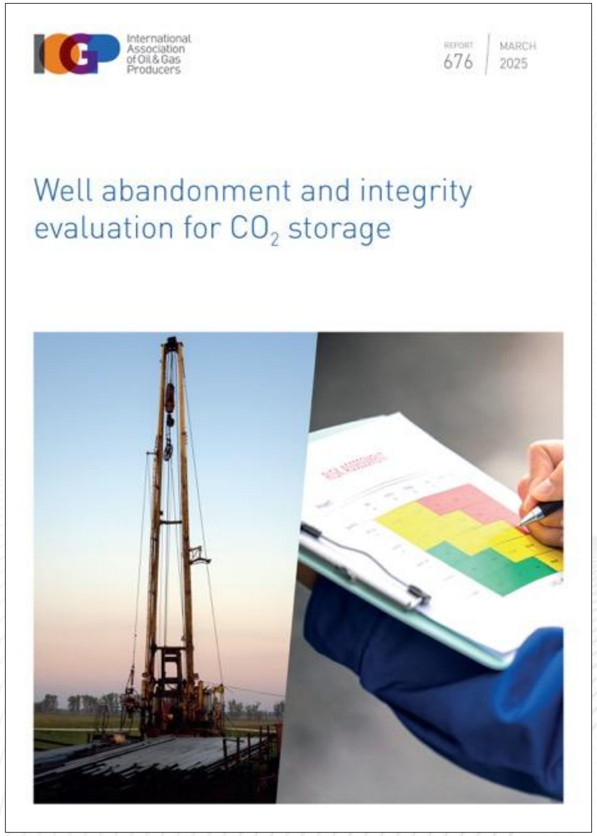
The purpose of permanent abandonment barriers is to restore the sealing unit [caprock/confining zone] where it is penetrated by the well and to isolate zones with flow potential from the surface and from one another. In some jurisdictions, isolation at the source [across the perforation or open hole interval] may be accepted.

The specific requirements for the length of abandonment plugs or annular cement included as barrier elements in an abandoned well will vary from one jurisdiction to another. Often, an environmental or 'surface' plug is placed in addition to primary and secondary well barriers to prevent any residual fluid in the well from contaminating the environment.

Figure 1 - An example well barrier schematic for P&A wells

Use Cases

- This Report is intended for wells personnel and industry stakeholders involved in a CCS project, specifically in the evaluation, planning, and execution phases.
- It provides guidelines for well barrier philosophy and material consideration for P&A of wells in the project area and recommends well integrity evaluation approaches for wells.



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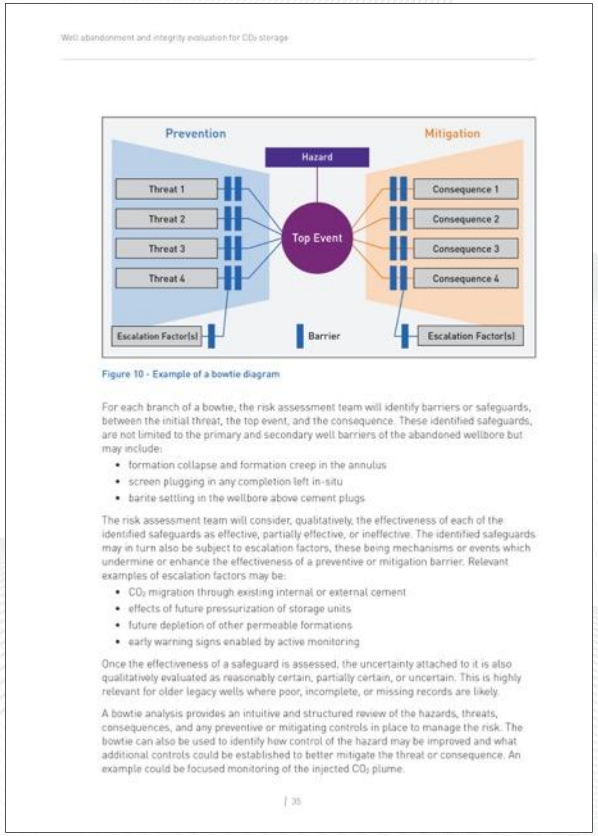
Well abandonment and integrity evaluation for CO_2 storage



Well abandonment and integrity evaluation for CO_2 storage

Figure 10 - Example of a bowtie diagram

For each branch of a bowtie, the risk assessment team will identify barriers or safeguards, between the initial threat, the top event, and the consequence. These identified safeguards, are not limited to the primary and secondary well barriers of the abandoned wellbore but may include:

- formation collapse and formation creep in the annulus
- screen plugging in any completion left in-situ
- barite settling in the wellbore above cement plugs

The risk assessment team will consider, qualitatively, the effectiveness of each of the identified safeguards as effective, partially effective, or ineffective. The identified safeguards may in turn also be subject to escalation factors, these being mechanisms or events which undermine or enhance the effectiveness of a preventive or mitigation barrier. Relevant examples of escalation factors may be:

- CO_2 migration through existing internal or external cement
- effects of future pressurization of storage units
- future depletion of other permeable formations
- early warning signs enabled by active monitoring

Once the effectiveness of a safeguard is assessed, the uncertainty attached to it is also qualitatively evaluated as reasonably certain, partially certain, or uncertain. This is highly relevant for older legacy wells where poor, incomplete, or missing records are likely.

A bowtie analysis provides an intuitive and structured review of the hazards, threats, consequences, and any preventive or mitigating controls in place to manage the risk. The bowtie can also be used to identify how control of the hazard may be improved and what additional controls could be established to better mitigate the threat or consequence. An example could be focused monitoring of the injected CO_2 plume.

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Report Sections in more detail

Principles of well plugging and abandonment for CO_2 storage projects

- Well types relevant to CCS
- Barrier philosophy
- Barrier considerations
- Challenges
- Verification of barriers for permanent abandonment

Plugging and abandonment for Project wells in CO_2 storage Projects

- Well plugging and abandonment guidelines
- Timing and Approach
- Well integrity evaluation

Plugging and abandonment for Legacy Wells in CO_2 Storage Projects

- Barrier philosophy
- Legacy well integrity evaluation process
- Uncertainty management and risk assessment
- Legacy wells risk scenario outcomes

Project Wells

- Guidelines for the abandonment of CO_2 storage project wells, including well integrity evaluation, prioritization, timing, and approach.
- Prioritization based on risk factors such as CO_2 plume contact, communication with zones of flow potential, and well integrity issues.
- Verification of well barrier elements is required, including cement bond logging, tagging of cement plugs, and inflow testing.

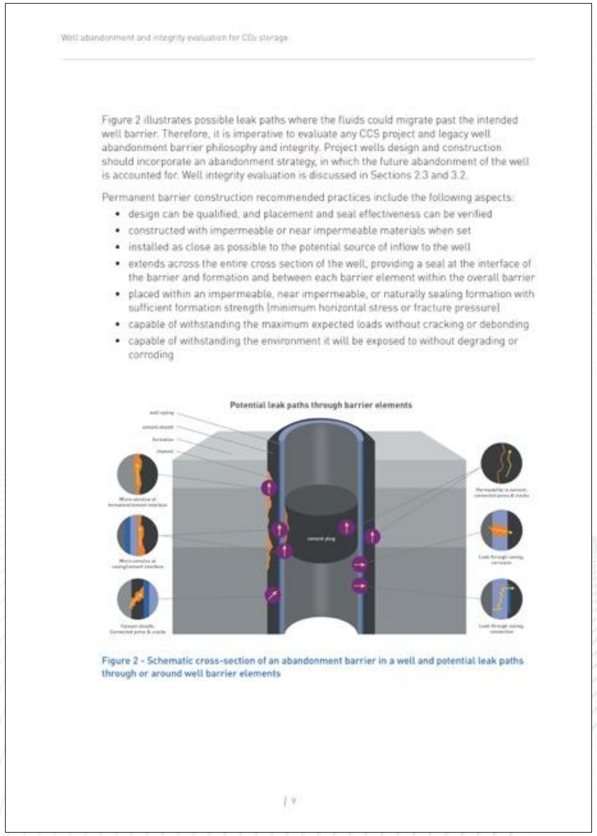
Well abandonment and integrity evaluation for CO_2 storage

Figure 2 illustrates possible leak paths where the fluids could migrate past the intended well barrier. Therefore, it is imperative to evaluate any CCS project and legacy well abandonment barrier philosophy and integrity. Project wells design and construction should incorporate an abandonment strategy, in which the future abandonment of the well is accounted for. Well integrity evaluation is discussed in Sections 2.3 and 3.2.

Permanent barrier construction recommended practices include the following aspects:

- design can be qualified, and placement and seal effectiveness can be verified
- constructed with impermeable or near impermeable materials when set
- installed as close as possible to the potential source of inflow to the well
- extends across the entire cross section of the well, providing a seal at the interface of the barrier and formation and between each barrier element within the overall barrier
- placed within an impermeable, near impermeable, or naturally sealing formation with sufficient formation strength (minimum horizontal stress or fracture pressure)
- capable of withstanding the maximum expected loads without cracking or debonding
- capable of withstanding the environment it will be exposed to without degrading or corroding

Figure 2 - Schematic cross-section of an abandonment barrier in a well and potential leak paths through or around well barrier elements

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Well abandonment and integrity evaluation for CO_2 storage

2. Plugging and abandonment for project wells in CO_2 storage projects

Following the operating life of a CO_2 storage project, all wells constructed during the development of the storage complex will require permanent abandonment. This section provides guidance for the abandonment of CO_2 storage project wells and the well integrity evaluation.

Project wells are those wellbores used to develop and operate a CO_2 storage project, which includes:

- CO_2 injector wellbores; either new wells, planned sidetrack wellbores, or wells re-purposed through workover
- exploration, appraisal, confirmation, or verification wells drilled to confirm the stratigraphy of a storage complex and suitability of a saline aquifer or depleted field for CO_2 injection, to de-risk the geological properties of the storage complex, and to estimate the committable storage capacity of the storage complex
- observation wells drilled or re-purposed from other project wells for monitoring purposes in the storage complex
- pressure management wells drilled to remove formation water displaced by injected CO_2 to mitigate pressure increases which may risk caprock integrity or fault reactivation
- injection or disposal wells for produced water from pressure management wells
- intercept wells for abandonment or remedial re-abandonment of inaccessible legacy wells that cross the storage complex
- other project wells which may be re-purposed for monitoring once their injection objectives are achieved, leading to a longer total well life than originally planned

To meet the requirement for safe permanent storage of injected CO_2, injection wells should be plugged and abandoned upon cessation of injection. Operators may be required by regulators to continue monitoring the storage project after wells are permanently abandoned upon closure of the site. The operator may consider the possibility of abandoning the reservoir section of selected wells while maintaining access to the overburden sections of the well during the monitoring period. Post-closure monitoring may include monitoring the abandoned wells at the surface or seabed for evidence of leakage.

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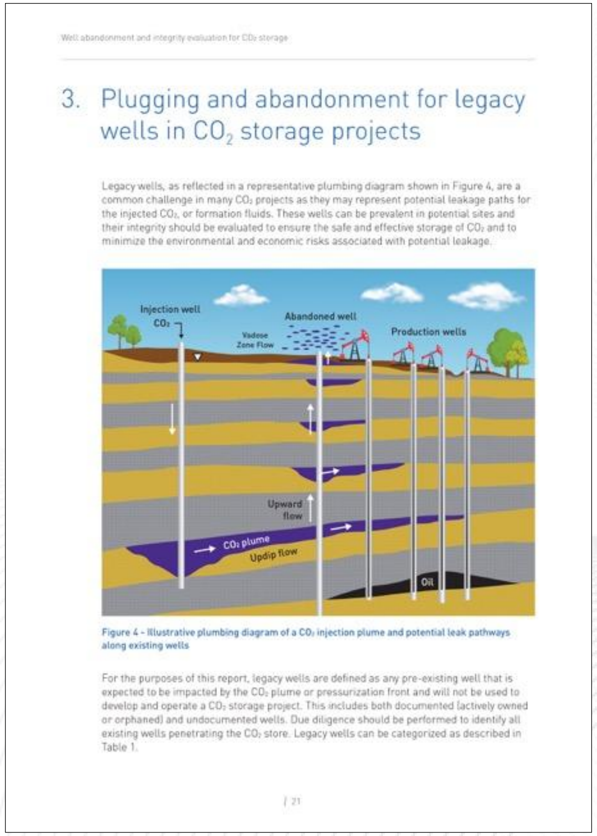
Legacy Wells

- Guidelines specific to legacy wells present in CO2 storage projects, including barrier philosophy, integrity evaluation process and uncertainty management and risk assessment.

- A risk-based approach is recommended to evaluate the suitability of legacy wells for CO_2 storage. This involves identifying barriers, assessing the likelihood of leakage, evaluating the consequences, and implementing appropriate mitigation measures.



Well abandonment and integrity evaluation for CO_2 storage

3. Plugging and abandonment for legacy wells in CO_2 storage projects

Legacy wells, as reflected in a representative plumbing diagram shown in Figure 4, are a common challenge in many CO_2 projects as they may represent potential leakage paths for the injected CO_2, or formation fluids. These wells can be prevalent in potential sites and their integrity should be evaluated to ensure the safe and effective storage of CO_2 and to minimize the environmental and economic risks associated with potential leakage.

Figure 4 - Illustrative plumbing diagram of a CO_2 injection plume and potential leak pathways along existing wells

For the purposes of this report, legacy wells are defined as any pre-existing well that is expected to be impacted by the CO_2 plume or pressurization front and will not be used to develop and operate a CO_2 storage project. This includes both documented (actively owned or orphaned) and undocumented wells. Due diligence should be performed to identify all existing wells penetrating the CO_2 store. Legacy wells can be categorized as described in Table 1.

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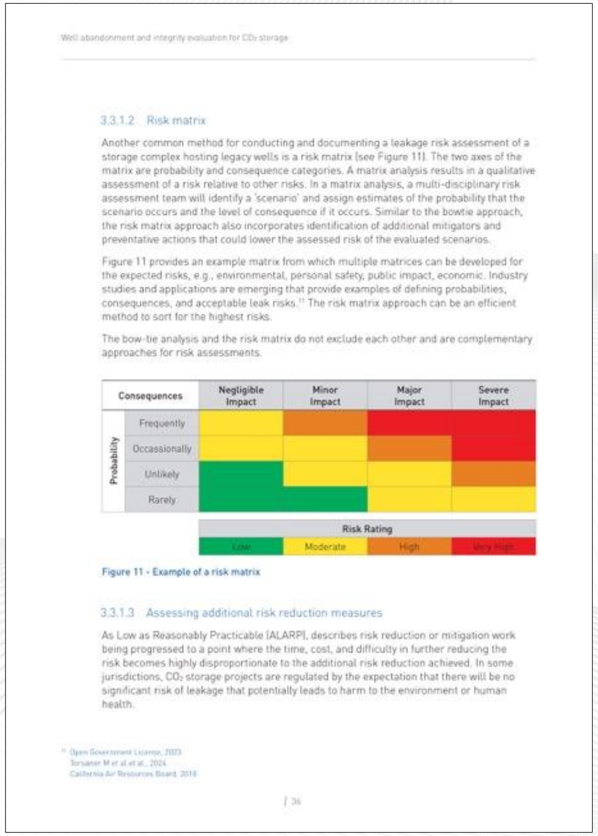

Well abandonment and integrity evaluation for CO_2 storage

3.3.1.2 Risk matrix

Another common method for conducting and documenting a leakage risk assessment of a storage complex hosting legacy wells is a risk matrix (see Figure 11). The two axes of the matrix are probability and consequence categories. A matrix analysis results in a qualitative assessment of a risk relative to other risks. In a matrix analysis, a multi-disciplinary risk assessment team will identify a 'scenario' and assign estimates of the probability that the scenario occurs and the level of consequence if it occurs. Similar to the bowtie approach, the risk matrix approach also incorporates identification of additional mitigators and preventative actions that could lower the assessed risk of the evaluated scenarios.

Figure 11 provides an example matrix from which multiple matrices can be developed for the expected risks, e.g., environmental, personal safety, public impact, economic. Industry studies and applications are emerging that provide examples of defining probabilities, consequences, and acceptable leak risks.[11] The risk matrix approach can be an efficient method to sort for the highest risks.

The bow-tie analysis and the risk matrix do not exclude each other and are complementary approaches for risk assessments.

Consequences		Negligible Impact	Minor Impact	Major Impact	Severe Impact
Probability	Frequently				
	Occassionally				
	Unlikely				
	Rarely				

Risk Rating			
Low	Moderate	High	Very High

Figure 11 - Example of a risk matrix

3.3.1.3 Assessing additional risk reduction measures

As Low as Reasonably Practicable (ALARP), describes risk reduction or mitigation work being progressed to a point where the time, cost, and difficulty in further reducing the risk becomes highly disproportionate to the additional risk reduction achieved. In some jurisdictions, CO_2 storage projects are regulated by the expectation that there will be no significant risk of leakage that potentially leads to harm to the environment or human health.

[11] Open Government License, 2023
Torsæter M et al et al., 2024
California Air Resources Board, 2018

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Well Integrity Evaluation

- Detailed explanation of the well integrity evaluation process for both project and legacy wells, including geological background, CO_2 plume migration, and pressurization.

- The evaluation process involves identifying and validating the location of legacy wells, performing and documenting an evaluation of historical documents, and assessing the integrity of each well.

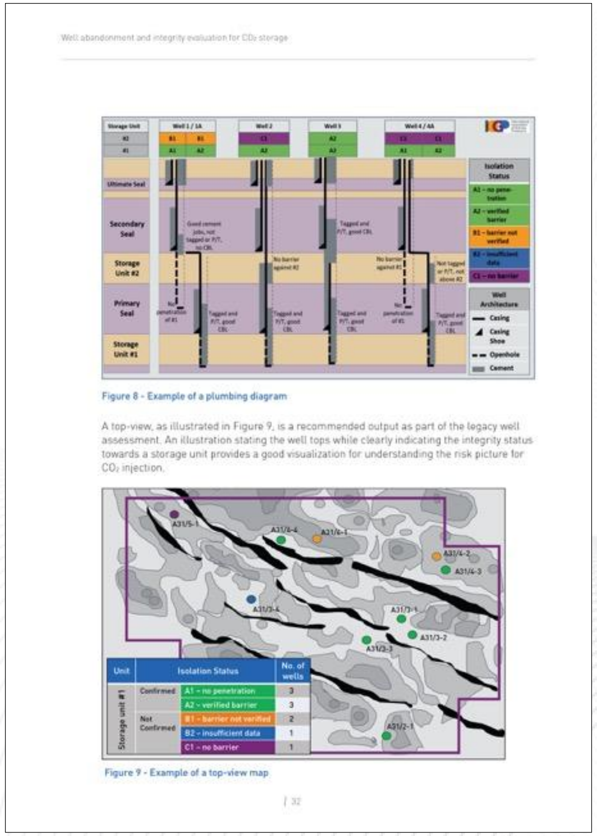
Well abandonment and integrity evaluation for CO_2 storage

Figure 8 - Example of a plumbing diagram

A top-view, as illustrated in Figure 9, is a recommended output as part of the legacy well assessment. An illustration stating the well tops while clearly indicating the integrity status towards a storage unit provides a good visualization for understanding the risk picture for CO_2 injection.

Figure 9 - Example of a top-view map

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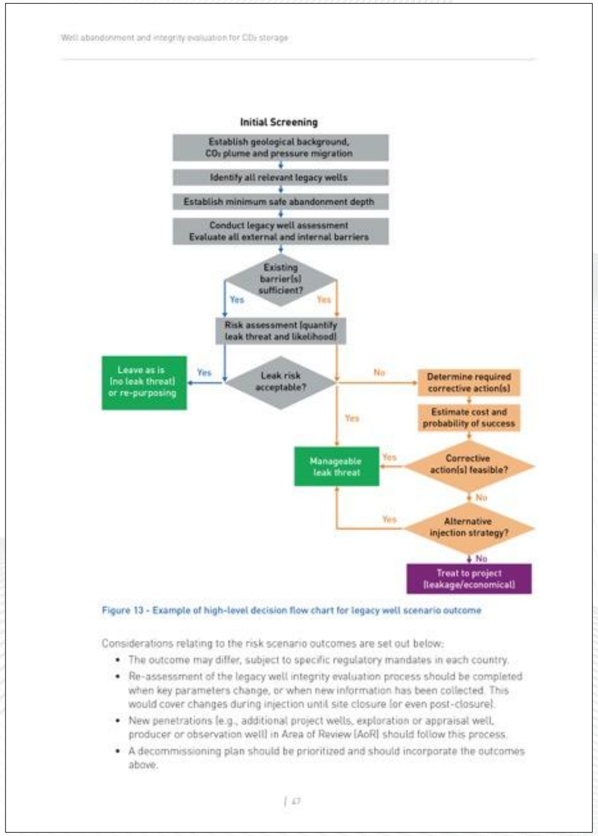
Well abandonment and integrity evaluation for CO_2 storage

Figure 13 - Example of high-level decision flow chart for legacy well scenario outcome

Considerations relating to the risk scenario outcomes are set out below:

- The outcome may differ, subject to specific regulatory mandates in each country.
- Re-assessment of the legacy well integrity evaluation process should be completed when key parameters change, or when new information has been collected. This would cover changes during injection until site closure (or even post-closure).
- New penetrations (e.g., additional project wells, exploration or appraisal well, producer or observation well) in Area of Review (AoR) should follow this process.
- A decommissioning plan should be prioritized and should incorporate the outcomes above.

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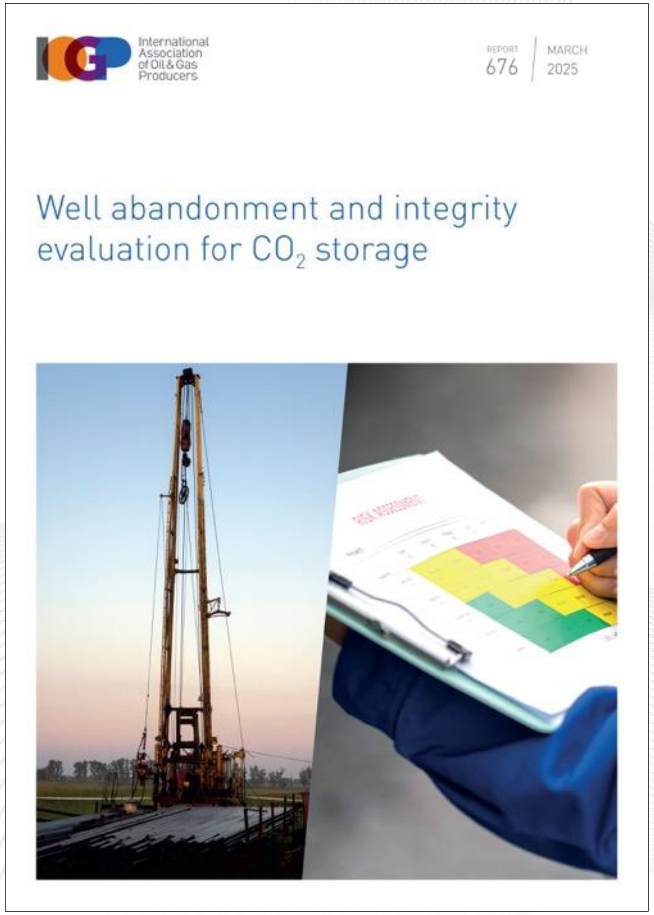
Conclusion

- CCS remains an emerging industry in comparison to oil and gas exploration and production.
- The Report aims to provide CCS operators with guidance and primary considerations for well abandonment and integrity evaluation for CO_2 storage projects.
- It is not intended to be exhaustive nor supersede any presiding regulatory requirements.



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