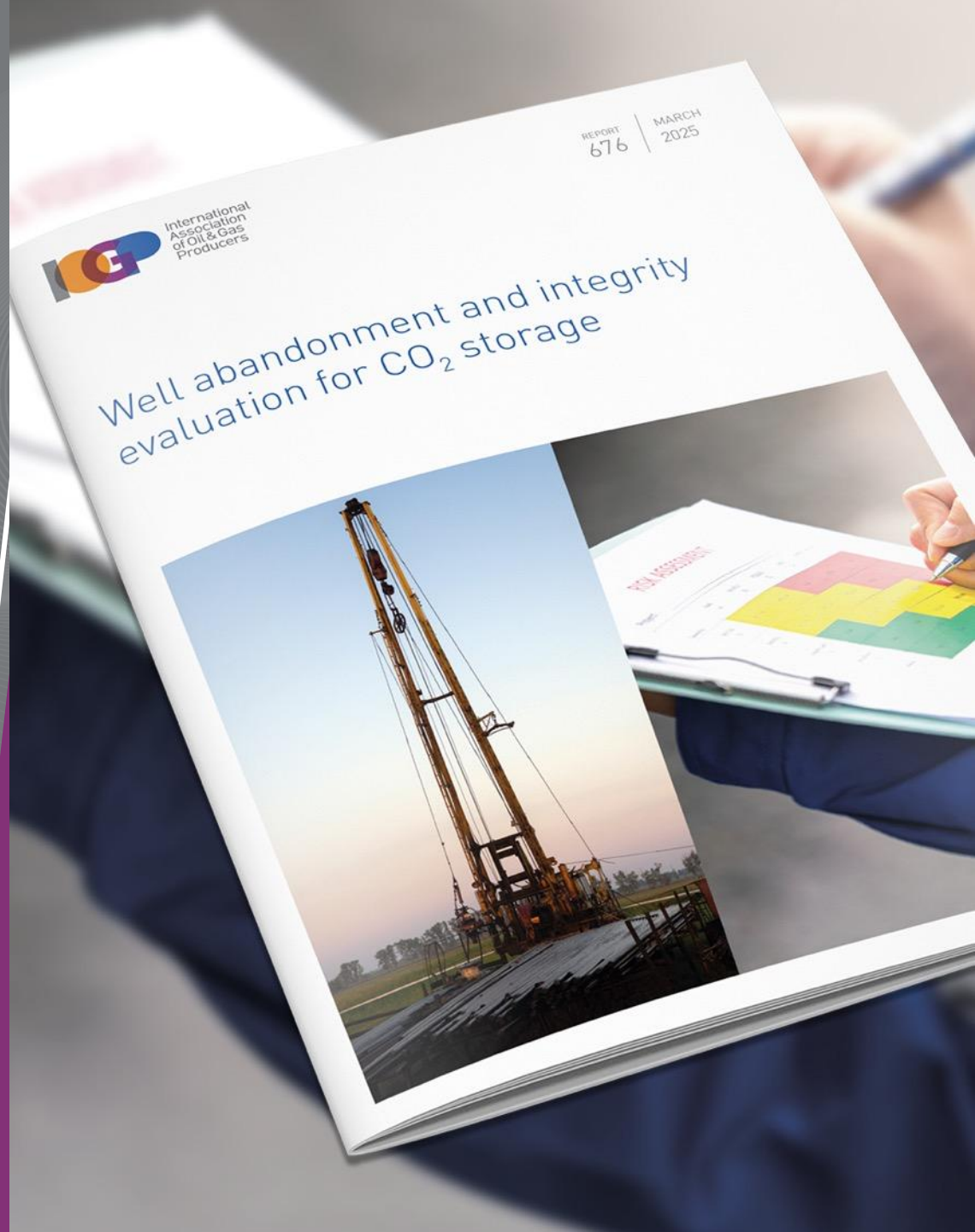
International Association of Oil & Gas Producers

Well abandonment and integrity evaluation for CO_2 storage

Russell Haley

SPE CO2 Storage Conference

September / October 2025



Our purpose

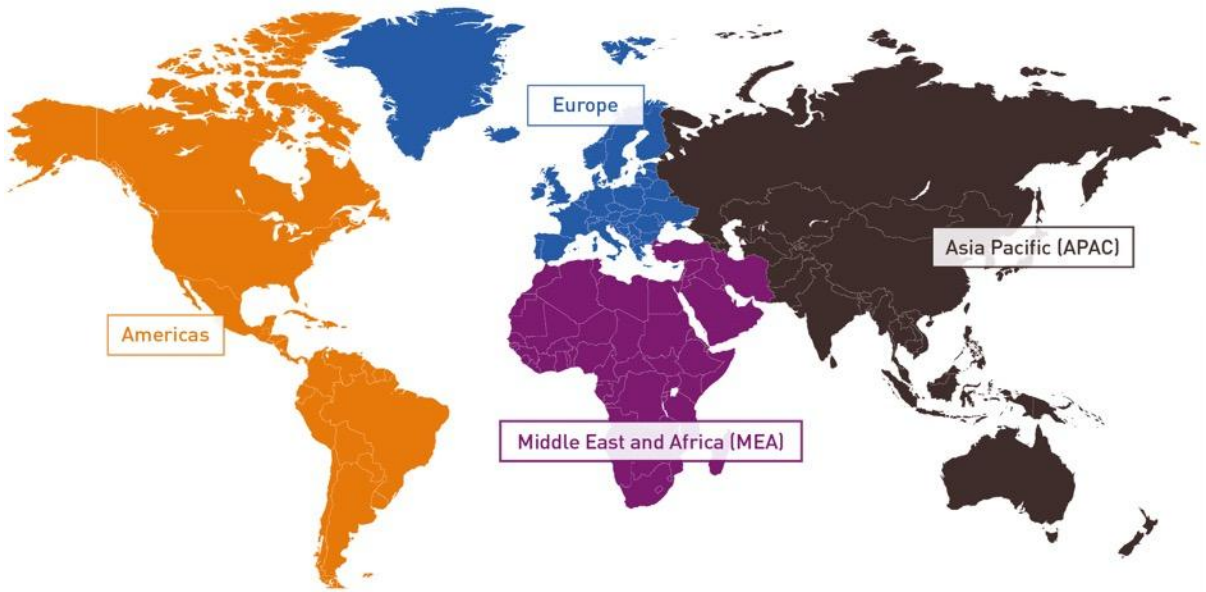
Building on our strengths and enabling a low carbon future

International Association of Oil & Gas Producers

We are the global voice of our **industry**,
pioneering excellence in **safe**, **efficient** and **sustainable energy supply**
- an **enabling partner** for a **low carbon future**

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
ConocoPhillips
EnerGeo Alliance
ExxonMobil
Hess
IADC
IBP
Kosmos Energy
Oxy
Pan American Energy
Pemex
Petrobras
Pluspetrol
Prio
SLB
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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
Qatar Energy
Sonangol

Europe

Aker BP
Aker Solutions
Assala Energy
bp
BVEG
BW Energy
Capricorn Energy
Centrica (Spirit Energy)
Cepsa E&P
DNV
Element NL
Energy Institute
Eni SpA
Equinor
Galp
Harbour Energy
HeliOffshore
Ipieca
Ithaca Energy
MOL
Offshore Energies UK
Offshore Norge
OMV
ORLEN S.A.
Perenco
Repsol
RomGaz
Saipem
SBM Offshore
Shell
Subsea7
TechnipFMC
TotalEnergies
Trident Energy
Tullow Oil
Vår Energi
Viaro Energy

Asia Pacific (APAC)

Australian Energy Producers
Beach Energy
Brunei Shell Petroleum
CNOOC International
INPEX
KazMunayGas
NCOC
ONGC
PETRONAS Carigali
Prime Energy
PT Pertamina Hulu Energi
PTTEP
Reliance
SOCAR
Woodside Energy

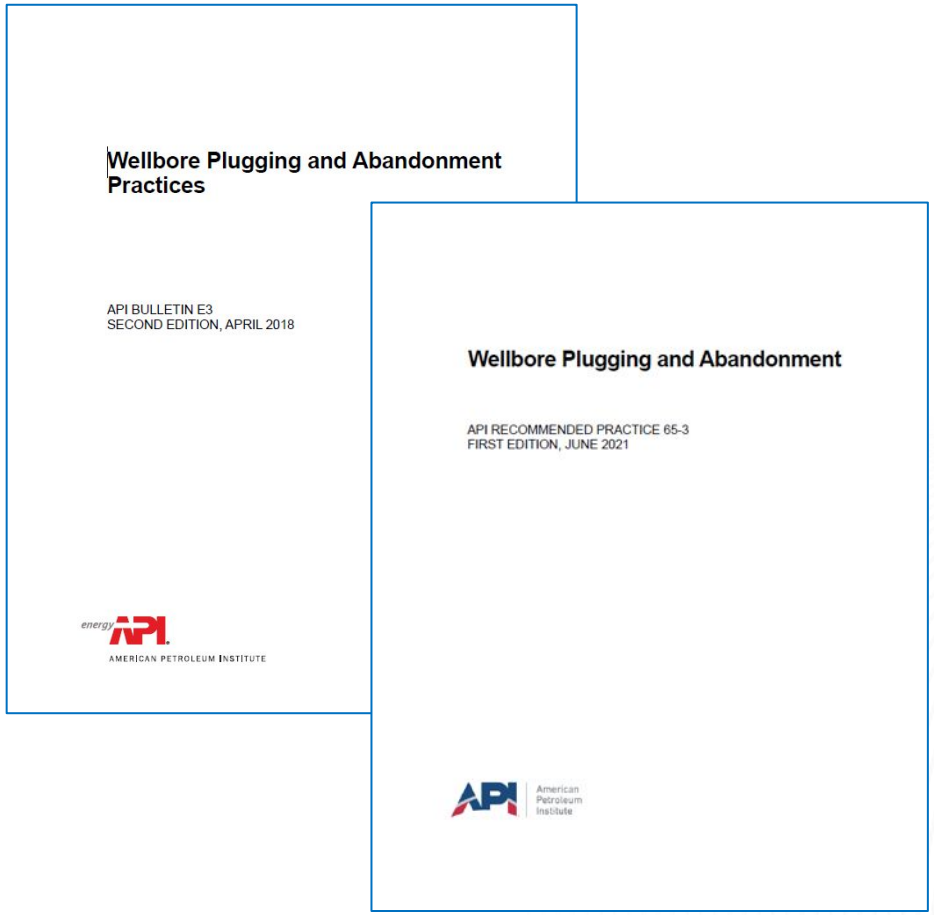
Business case / scope

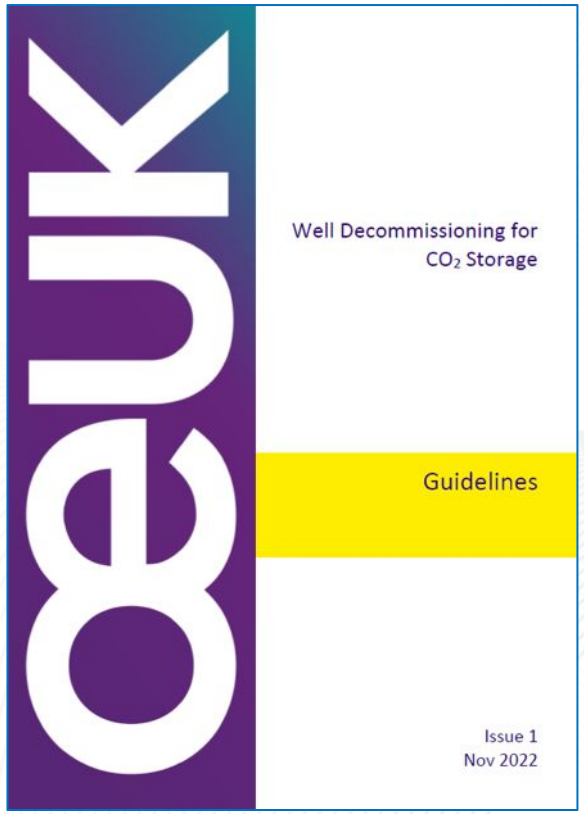
No industry standard addresses well P&A in the context of storage containment risk

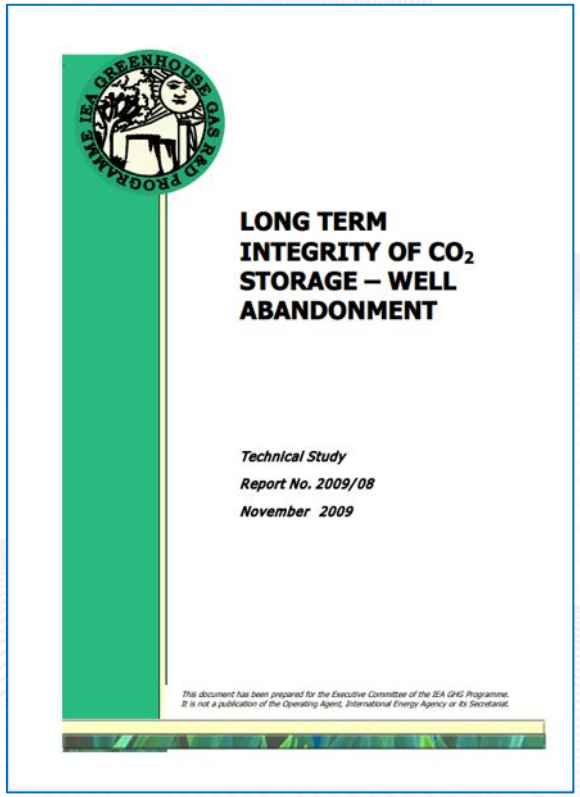
Assess framework for integrity of wells within CCS storage projects:

- Gain alignment among operators and develop operator requirements for well abandonment integrity
  - Leverage published industry Standards
- Provide framework for screening and assessing containment risk of legacy wells in storage project area
- Intentionally assess consistency of risk approach compared with oil and gas
- Address relevant technical issues such as cement integrity and degradation, stochastic leak probability, phase change / equations of state
  - Leverage published industry literature

Industry Standards and Guidelines on the Topic







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

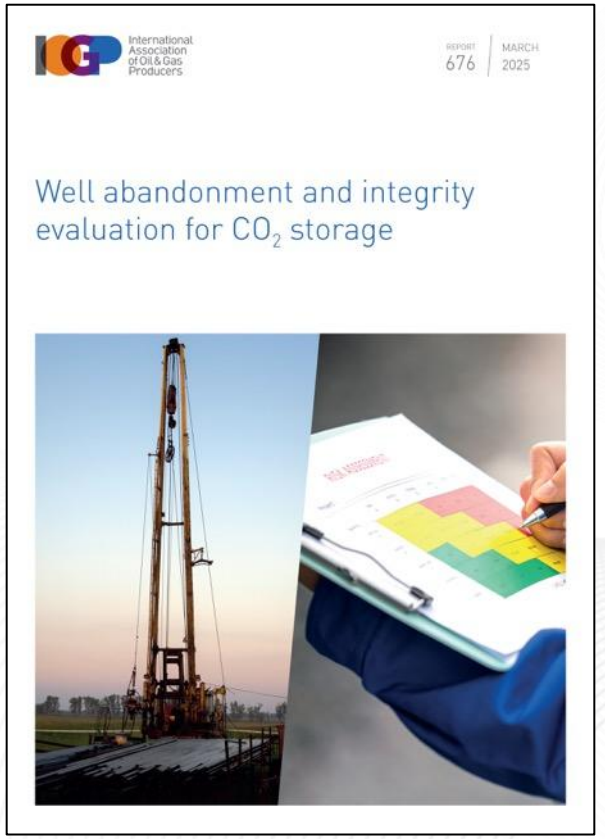
IOGP Report 676 - Overview

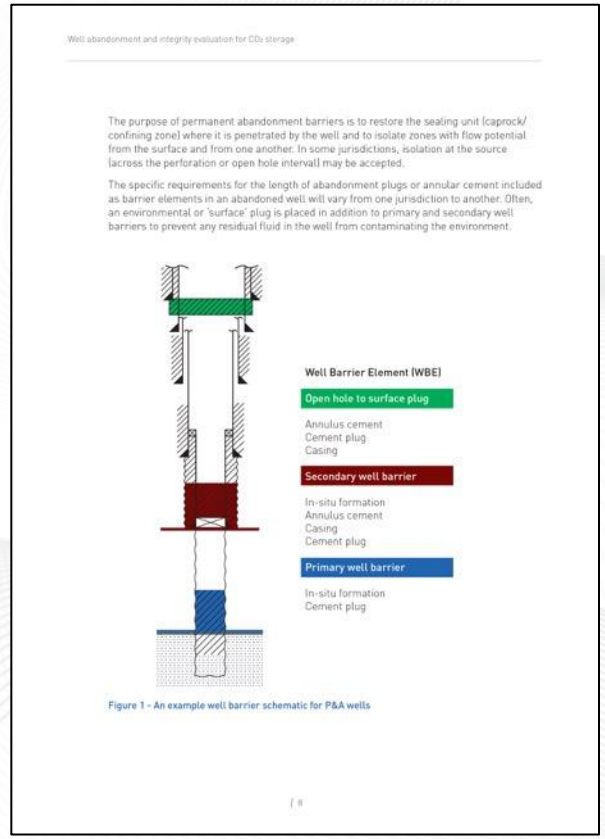
IOGP Report 676 is written as guidance, not a specification or requirement

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

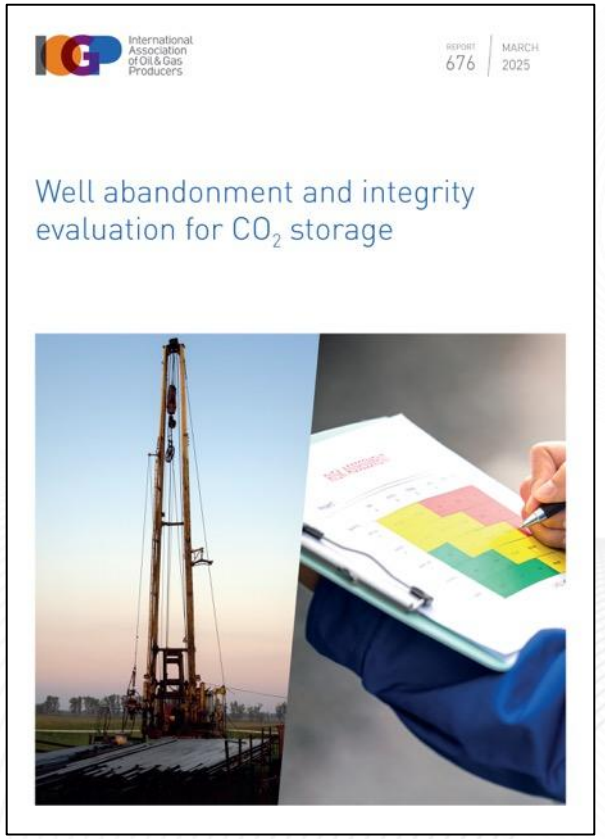
- Principles of well plugging and abandonment
- Plugging and Abandonment for Project wells
- Plugging and Abandonment for Legacy Wells
- Appendix – Well types and Conditions

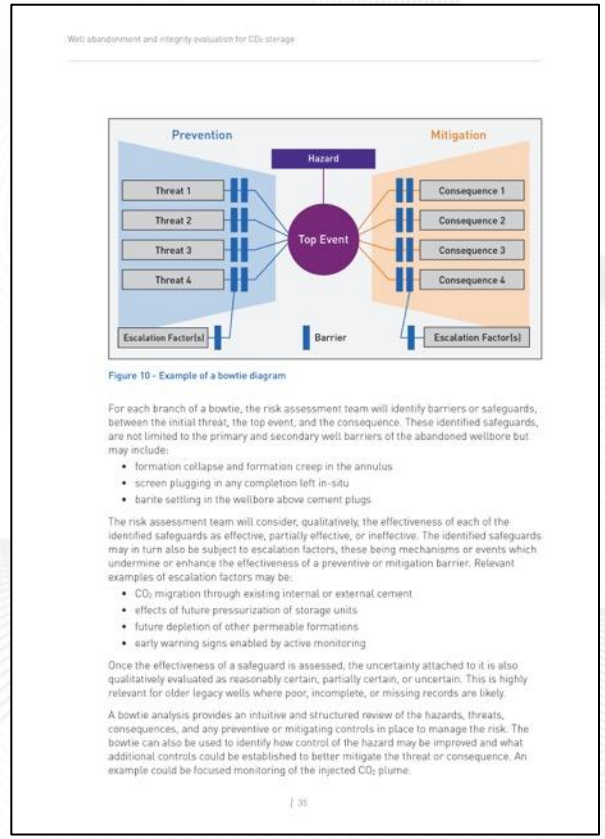




Use Cases

- 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.





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

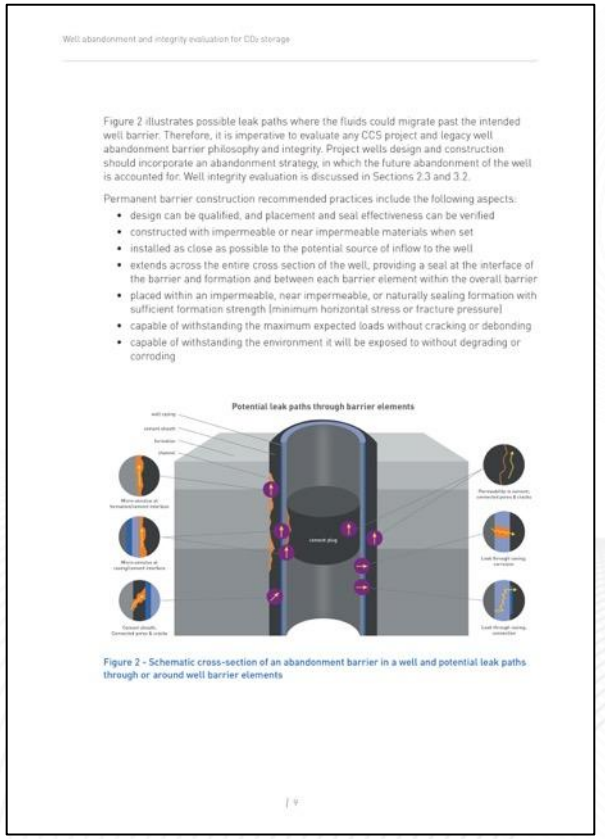
- Well plugging and abandonment guidelines
- Timing and Approach
- Well integrity evaluation

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

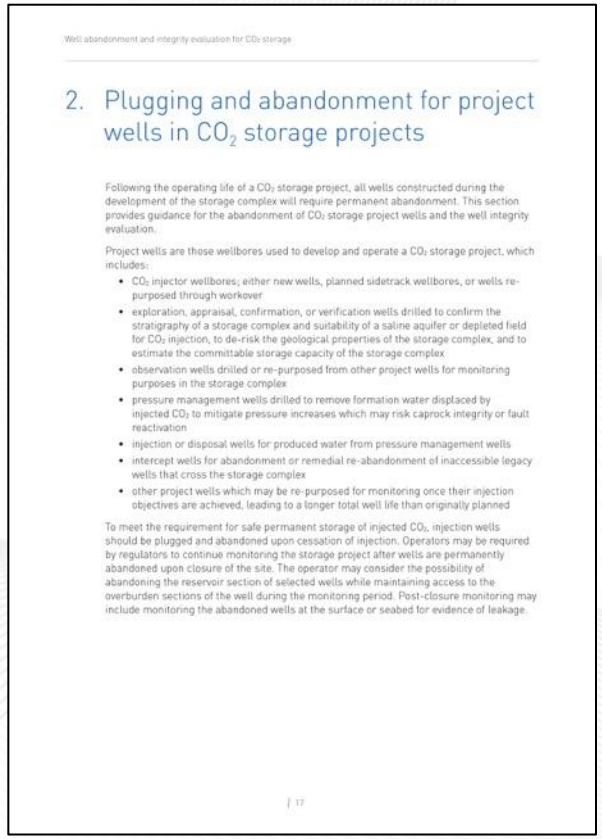
Figure 2 illustrates possible leak paths where the fluids could migrate past the intended well barrier. Therefore, it is imperative to evaluate any CCS project and legacy well abandonment barrier philosophy and integrity. Project wells design and construction should incorporate an abandonment strategy, 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

Potential leak paths through barrier elements

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



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:

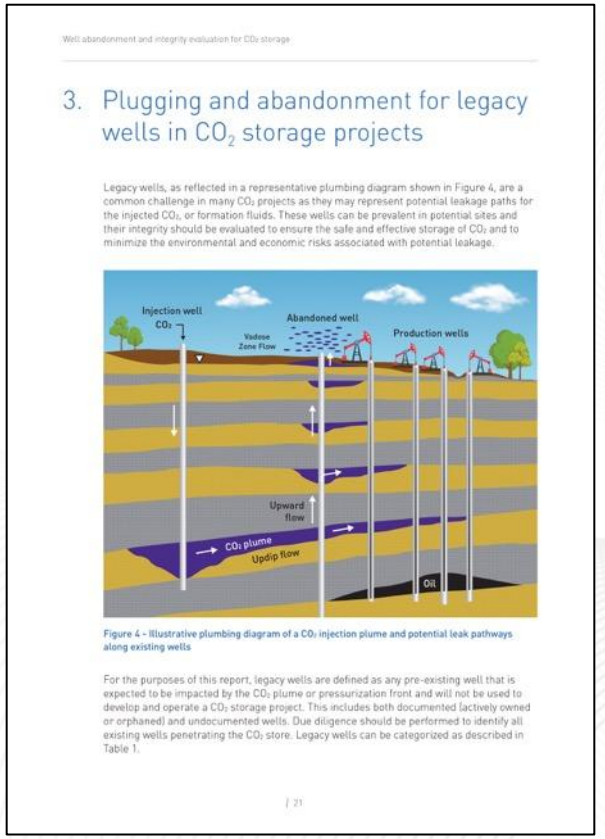
- CO_2 injector wellbores; either new wells, planned sidetrack wellbores, or wells re-purposed through workover
- exploration, appraisal, confirmation, or verification wells drilled to confirm the stratigraphy of a storage complex and suitability of a saline aquifer or depleted field for CO_2 injection, 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.

Legacy Wells

- Guidelines specific to legacy wells present in CO_2 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.



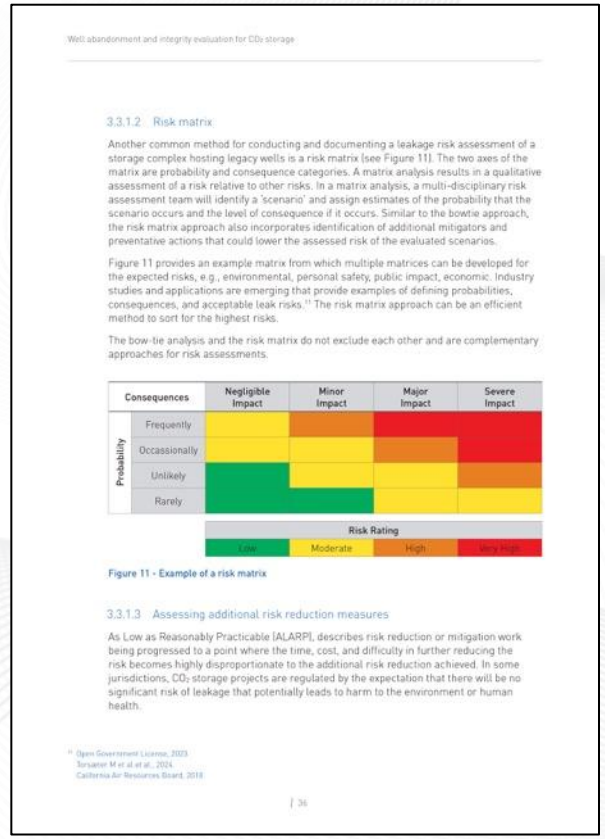
Well abandonment and integrity evaluation for CO_2 storage

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.



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				
Probability: Occassionally				
Probability: Unlikely				
Probability: Rarely				

Risk Rating: Low | Moderate | High | Very High

Figure 11 - Example of a risk matrix

3.3.1.3 Assessing additional risk reduction measures

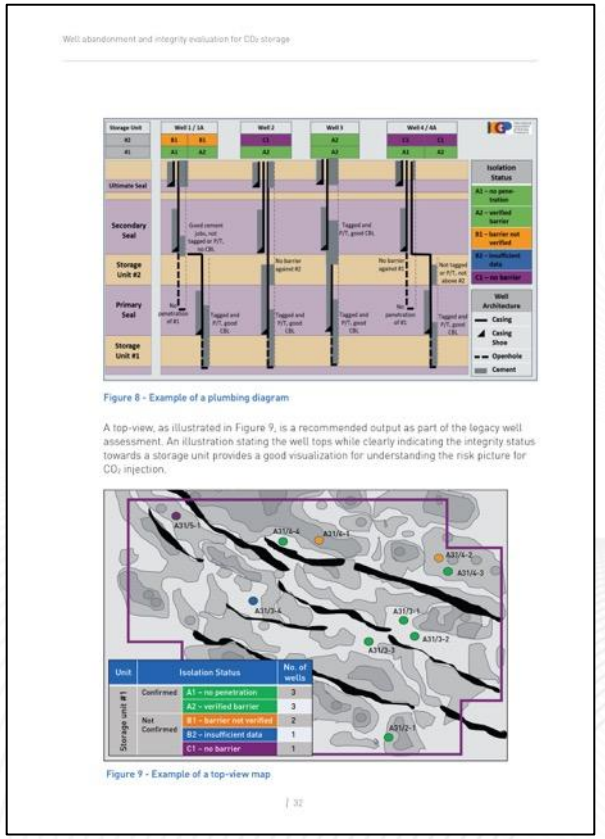
As Low as Reasonably Practicable (ALARP), describes risk reduction or mitigation work being progressed to a point where the time, cost, and difficulty in further reducing the risk becomes highly disproportionate to the additional risk reduction achieved. In some jurisdictions, CO_2 storage projects are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

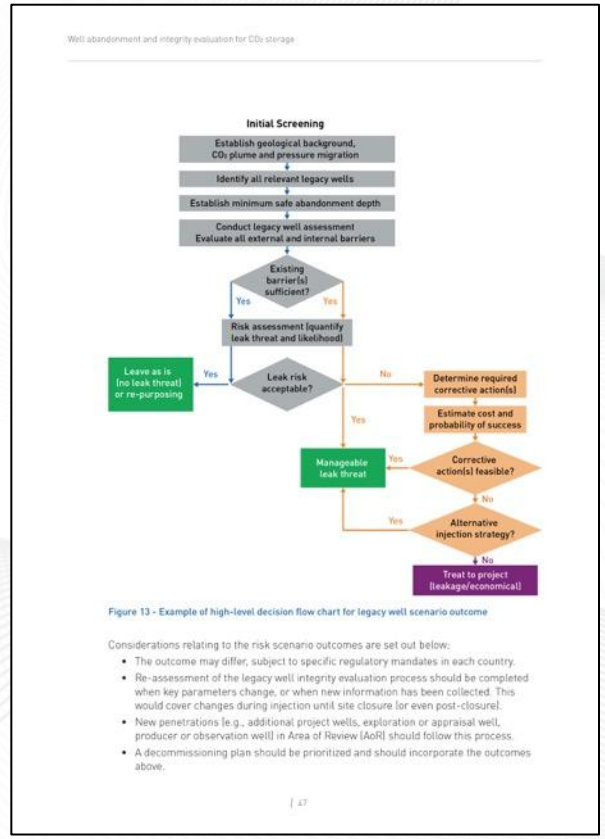
[11] Open Government License, 2023.
Torsæter M et al et al., 2024.
California Air Resources Board, 2018

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.





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.

International Association of Oil & Gas Producers

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