

Best Methods for Abandoning an Idle Oil Well and the Longevity of Wellbore Cement

Commentary by Jim Crompton, Vandan Bhalala,
and Brad Handler

Introduction

Plugging and abandoning an idle oil well is a critical process in oil and gas operations during the later stages of the life of a wellbore. Issues arise both from operational, environmental, safety and economic perspectives. An improperly abandoned well can result in hazardous leaks, environmental damage, and long-term financial liabilities. The oil industry has developed several best practices and standards to ensure that wells are sealed and abandoned properly. But there are several audiences for this guidance from the context of offering carbon credits for plugging orphan wells in a voluntary carbon market platform: for the project manager who is plugging the well, for the state inspector and for the buyer of carbon offset credits.

This commentary will discuss the best methods for abandoning an idle oil well, as well as the durability and longevity of cement barrier used in wellbores against leakage of methane gas. As part of the study at the Energy Finance Lab of using voluntary carbon offset markets as a source for private capital for orphan well methane abatement, the question of the permanence of plugging a well is an obvious one.

To quote from the National Academy white paper: *"The goal of any orphaned well program is to address environmental risk and human health and safety concerns in the most appropriate way possible. Addressing orphaned wells and facilities (equipment and infrastructure) provides immediate safety and environmental benefits. Every orphaned well may present unique challenges. Variations in well construction, well integrity, maintenance, local geology, geographic setting, and a multitude of other factors may present challenges on an individual well basis. Varying state, local, and in some cases, federal requirements must also be considered. Orphaned well programs must have the ability to plan and design for unique situations. They must also have*

the ability to address unforeseen issues during the plugging and remediation process.”

[https://nap.nationalacademies.org/resource/28035/White Paper Orphaned Wells Workshop Proceedings.pdf](https://nap.nationalacademies.org/resource/28035/White_Paper_Orphaned_Wells_Workshop_Proceedings.pdf)

For the project manager, plugging and abandoning an oil or gas well and cleaning up the site will have both engineering, documentation, and financial challenges. The question of P&A (plug and abandon) standards and even how long cement lasts in a plugging job have come up as questions in conferences dealing with voluntary carbon market offset credits for plugging an orphan well. Buyers of carbon emissions credits are often not familiar with oilfield practices and can have doubts on the transparency of emissions abatement (offset) credits or even the stability of a properly plugged well. It is up to the project manager to be transparent and to build trust for the market to work.

With the large number of small producers near the end of their economic life in the United States, other critics challenge whether producers properly account for end-of-life costs in accounting for profitability. We are just coming to grips with the very large magnitude of the inventory of orphan wells in the United States. An even larger number of wells are in the declining stage of production and will add to the challenge. This is not a problem that is going away anytime soon.

Statement of Philosophy: Introduction

While oil and gas operators are required to seal wells at the end of their productive lives, one hundred seventy years of oil and gas development has nonetheless left a massive inventory of so-called "orphan" wells across the United States — oil and gas wells that are inactive, unplugged, and have no solvent owner of record. The current inventory of about 120,000 documented orphan wells was developed to establish eligibility for federal funding under the Infrastructure Investment and Jobs Act of 2021, but estimates of additional undocumented orphan wells range from the many hundreds of thousands to several million in the U.S. alone.

These wells can pose significant risks to human and environmental health by leaking toxic chemicals into the air, contaminating groundwater, and emitting methane. The United States Environmental Protection Agency (EPA) estimated that methane emissions from over two million inactive, unplugged wells, of which documented orphan wells are a subset, range from a CO₂ equivalent of 7-20 million metric tons per year (approximately the emissions of two to five million cars). They can also lower property values and land productivity, with one study in Pennsylvania showing a 50% drop-off in building development in areas with high orphan well concentration. The call-to-action is clear.

Background

We believe that the responsibility for plugging abandoned and idle oil and gas wells should fall within the following four tiers.

1. Responsible operators should plug abandoned and idle wells that are a part of their permit commitments, account for the abandonment costs for their wells approaching their economic limit (pay for their retirement from current cashflow) and take responsibility of legacy wells drilled by prior operations on their leases as a condition for new drilling and production permits. The good

news is that many if not most operators in states with active oil and natural gas production are making good on their obligations. But this has not always been the case.

2. Public agencies (specifically state groups) can use public funding (drilling fees, surety bonds and federal grants) to work with authorized oil field service contractors to plug orphan wells under their authority, based on a transparent prioritization scheme responsible to public input.

3. Philanthropic funding by some organizations can raise funds to support contractors to plug abandoned wells that fall outside the state lists but present a specific risk to a community or individuals. While this support is welcome, the limited funding from this approach only goes so far.

4. But this leaves many legacy orphan wells and a growing list of micro-producers near the end of their economic life from operators without the finances to properly plug these wells. Rather than let them remain ignored, private voluntary carbon offset markets can be an avenue for responsible contractors to be rewarded for plugging these wells and recovering their costs. This creates a new business model for some emerging companies.

The focus of our study is on this fourth opportunity. However, there are important factors to consider like the question of additionality and whether it is acceptable to use carbon markets when there are government funds available, and e.g., is it ok that we raise funds based on "expected to emit" vs. actual current leak rates? In many cases with a low carbon price and very small emissions, it will be difficult for project managers to recover their costs from "micro-emitter" idle wells, which are the majority. But there is a category of "high emitter" wells where carbon markets can play a role in raising adequate capital.

Methodology approach

From the perspective of a buyer of carbon offset credits from a reputable trading market, carbon credits from plugging orphan wells should pass the tests of additionality, credibility of volume estimates, third-party verification of field operations and permanence of the well bore barrier. We recommend the following steps in such a methodology:

- **Physics Informed** Using a decline curve approach over a straight line projection from a well measurement test (or two) is already a "conservative" approach and corresponds to the scientific and operational body of knowledge of reservoir and production experiences from the Oil and Gas industry (including: the empirical Arps' equation (<https://www.education.psu.edu/png301/node/860>), fluid dynamics and reservoir characterization models).

- **Data Derived** Subsurface analysis can be very detailed and require a lot of technical data. The data available from most orphan wells is very limited due to poor record keeping by operators and regulatory agencies from wells abandoned decades ago. A number of these wells were abandoned before state agencies were even created. A substitute methodology using the data available (like public production history records) using statistical methods can approximate the decline curves behavior from industry reservoir experiences.

There are many different types of statistical approaches from hyperbolic and exponential decline (from Arps) to linear regression. We have used many of these methods in our analysis from segmenting by state/basin, by production rate, by depth/reservoir, by year etc. Each analysis

produces slightly different results but the good news is that the results fall into a narrow range (3.5 to 6%) over the later stage of a well history (last 20 years) and a cumulative average of all wells in our study provides a reasonable result to use in a decline rate standard. More detailed analysis does not produce a more accurate answer. Don't let a good answer be the enemy of the unreachable perfect result. (see companion article by Handler et al <https://payneinstitute.mines.edu/a-study-of-terminal-decline-rates-of-oil-gas-wells/>)

- **Be Consistent** Being consistent is more important than letting operators choose their own rates. It will be easier to compare credits with a clear, transparent, simple as practical, conservative approach. While it may be tempting to apply subsurface characterization methods as previously mentioned but the reality is most orphan wells that you come across will be difficult to find a complete, or even partial, production history. Some older orphan wells will be a complete mystery with little to no data available.

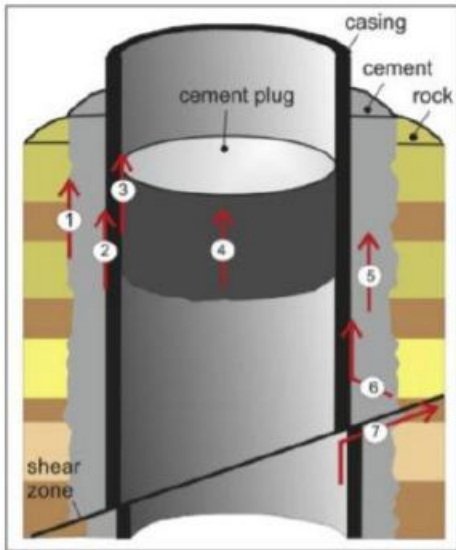
- **Be reasonable** Picking the high end of the range (say 6%) is more conservative on the operator's carbon offset credit volume but might be economically discouraging so the well doesn't get plugged. A result developed by averaging many wells provides a standard with a minimum amount of subjectivity. The project manager should use the data (historical production or several measurement points) if it is available, and then if it is not then using an accepted standard decline rate. Markets should be able to develop a practical solution.

- **For how Long?** The 20-year estimation period used in some carbon offset trading markets seems arbitrary. A 30-year estimation period or longer could be justified as this is close to the estimated time that the cement in the P&A job would last. The use of a decline curve brings a conservative (and hopefully trustworthy) element and a length of crediting period supported by field reality of current plugging practices is a reasonable compromise from many perspectives. Selecting any time-period for estimation of methane abatement adds conservatism to do so since the emissions would likely continue for as long as the well is not plugged. Again, Markets should be able to develop a practical solution.

Best Methods for Abandoning an Idle Oil Well

This section is directed to the project manager and to the state inspector. Proper abandonment of idle oil wells is essential for preventing environmental contamination and for the safety of surrounding communities. Industry standards and practices ensure that this process is conducted safely and efficiently. Several key methods and protocols have been established to guide this process, as outlined in various reports and standards, including the API Recommended Practice (RP) 65-3, 1st Edition, Wellbore Plugging and Abandonment, the National Petroleum Council guidelines and others including state-specific and even country-specific guidelines.

Potential Leak Paths in a Cemented Wellbore⁴⁸

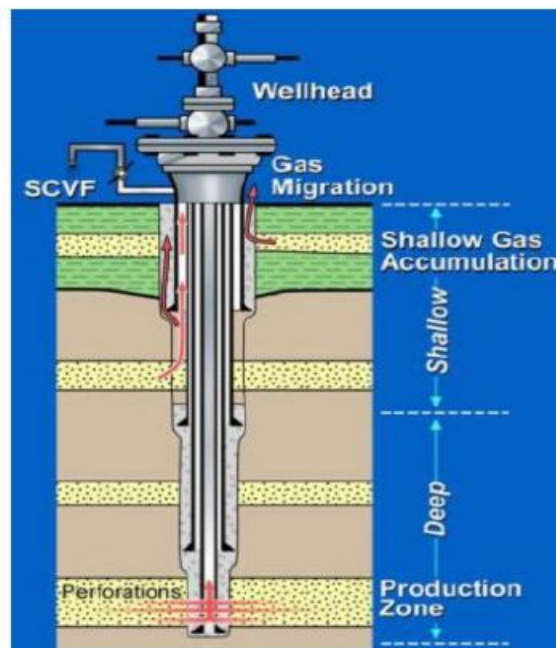


The label numbers represent the following:

1. Between cement and surrounding rock formations
2. Between casing and surrounding cement
3. Between cement plug and casing or production tubing
4. Through cement plug
5. Through cement between casing and rock formation
6. Across the cement outside the casing and then between this cement and the casing
7. Along a sheared wellbore

Appendix B: Reference Documents; Drilling and Completion Committee (DACC); IRP 27: Wellbore Decommissioning An Industry Recommended Practice (IRP) for the Canadian Oil and Gas Industry; Volume 27- 2022; Edition 1; Sanction Date: February 2022; Copyright held by Energy Safety Canada, 2022; Figure 5; pg. 41

Potential Leak Paths at Surface⁴⁹



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The development, production, decommissioning and restoration of oil and gas well sites may be regulated under federal, state, and local laws, regulations and permits. Development on federally-owned land is managed primarily by the Department of Interior, Bureau of Land Management or the Department of Agriculture, U.S. Forest Service. Subject to the Clean Water Act, U.S.EPA regulates discharges of water or wastes including storm water run-off from oil and gas drilling and production sites. The National Environmental Policy Act (NEPA) requires that oil and gas exploration on federal lands be analyzed to prevent environmental impacts. In addition, each of the states where oil and gas is produced have one or more agencies that permit wells and regulate the design, construction, location, spacing, operation, and abandonment of wells. These states also enforce environmental standards. https://nap.nationalacademies.org/resource/28035/White_Paper_Orphaned_Wells_Workshop_Proceedings.pdf

Well Plugging and Sealing

The most crucial step in the abandonment process is the proper plugging and sealing of the wellbore. This process involves filling the well with materials that prevent fluid and gas migration and isolate the wellbore from surrounding geological formations, especially aquifers used as public water sources. Plugging plans consider the well purpose, depth, and construction. Mechanical integrity and well reconstruction are also considered. The plugging rig and associated equipment must be sized for the well depth, anticipated pressure, casing weights and possible location restrictions.

“A basic, although critical, consideration is the selection of an appropriate plugging material for the specified physical or chemical well conditions that may be encountered. Factors such as well depth, bottom hole temperatures, flow or lost circulation zones, fracture gradients, fluid and gas composition, and original or modified well construction are a few of the parameters requiring review as plugging materials are considered. Regulatory program statutes or regulations may simply establish certain performance criteria as a basis for plug material selection and approval. Initial minimum compressive strength, usually in a 12 or 24 hour time, is an example of a basic selection parameter. Plugging material that meets or exceeds the established standards may qualify the material for use. Some regulatory programs maintain a list of approved plugging materials. Others may define approved materials in law. The use of alternate plugging materials may be necessary if there are material shortages or if specific well conditions are better addressed by such materials. Some programs have the legal authority to consider the use of alternate plugging materials while others may have narrowly drafted regulations that limit or prohibit their use.”

https://nap.nationalacademies.org/resource/28035/White_Paper_Orphaned_Wells_Workshop_Proceedings.pdf

The steps typically involved in plugging a well include:

Cementing: Various types or classes of Portland cement are the most common plugging material used by the oil and gas industry. It must be applied at strategic points along the wellbore to isolate

porous formations and prevent the flow of fluids (API RP 65-3: Wellbore Plugging and Abandonment provides guidance for barrier design, materials, and placement.). The cementing procedure involves setting plugs at predetermined depths and ensuring the cement bonds effectively to both the casing and the rock formations. Proper cementing is vital to prevent future leaks or gas migration.

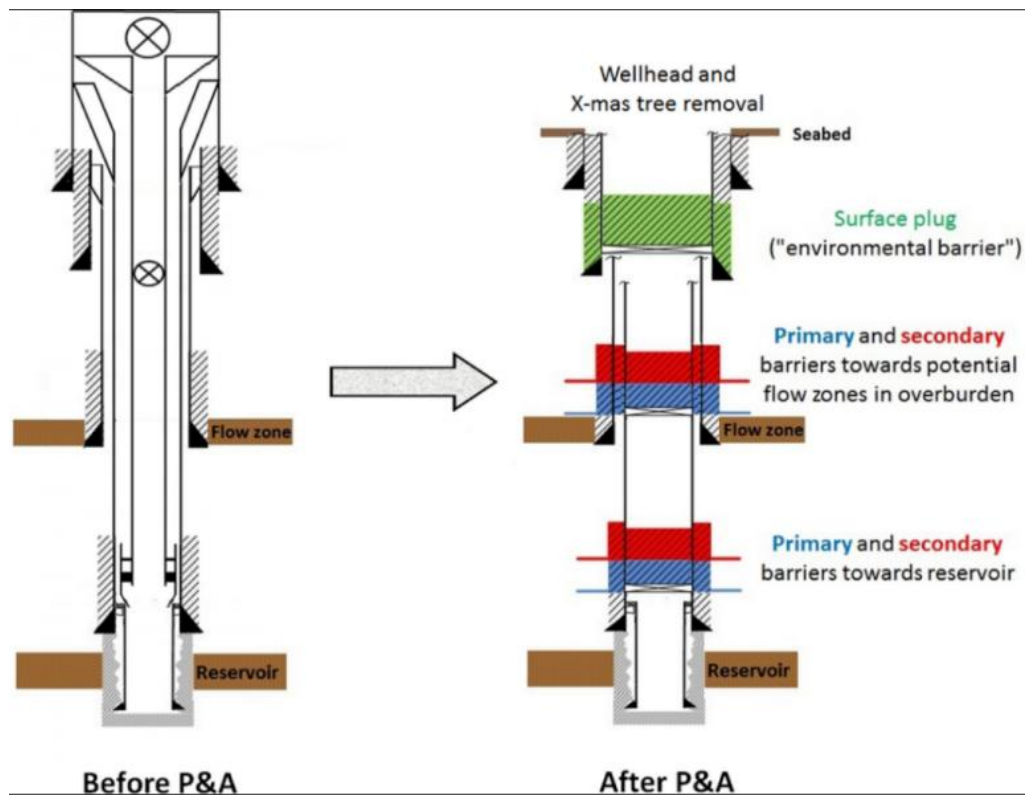
Mechanical Plugs: In addition to cement, mechanical plugs may be placed at the surface of the wellbore or at key points downhole to ensure the integrity of the seal. These plugs are typically designed to hold the cement in place and prevent any potential migration of fluids. Failure to place appropriate plugs at all is responsible for many discharges.

Wellbore Cleaning: Prior to cementing, the wellbore is cleaned to remove any debris or liquids that may interfere with the cement bond. This can include circulating fluids to remove excess oil, gas, and other debris that may be present. Often pulling surface casing and production liners are part of preparing a wellbore for abandonment.

Verification and Testing: After the well is plugged, a series of tests are conducted to verify the integrity of the plug. This may involve pressure tests to ensure there is no leakage, as well as logging tools to measure the cement bond and the effectiveness of the seal. The need for third-party oversight, observation, and documentation of the project is essential to develop trust and confidence.

After a well has been plugged, the wellbore may be monitored for indicators of plug failure. Monitoring may be necessary for several days. Offset wells may also be monitored periodically for signs of re-pressurization. Extended testing of abandoned wells to ensure there are no methane leaks is desired but takes a lot more effort by the project manager. Responsible project teams will monitor a well for several months after plugging a well but even longer studies (1-3 years) would provide greater confidence that methane emissions have been contained.

This work is not for amateurs. Proven industry experience with an eye towards quality and a solid safety-culture is essential. Project managers with this resume should be rewarded with a well-earned reputation by carbon offset market activities.



<https://www.assetintegrityengineering.com/aie-strategic-approach-for-wells-plug-and-abandonment/>

Cement is currently used in wells as the prime material for abandonment purposes as it is found to have similar properties to the rock that it is replacing. However, given its operational limitations, alternative materials (like a cement hybrid using biochar or epoxy), which can offer advantages over cement, are being proposed and developed by the industry and materials researchers. These substances, however, still will not replace cement in most cases. When compared with cement that has been used for decades, the use of new materials creates uncertainty with regards to long-term integrity, and acts as disincentive for their use.

But, as wells are drilled in new geologic settings, the physical properties of target zones may require new or modified materials. New or modified materials may not be specifically approved for use, but the initial use of such materials may be allowed by regulators if it is demonstrated that they meet or exceed certain performance standards. In some cases, new or modified materials may then be used without the need to update legal authority.

Here are three examples of recent studies about cement alternatives; Research into novel solutions such as biomineralization technology hold the promise of improving cementing of abandoned wellbore and stopping methane leaks. As one example, in 2014, the Montana State University Center for Biofilm Engineering (CBE) was given \$8 million from the Department of Energy to research how microbes could be used to seal problematic defects in wellbore casing cement. The research team, including BioSqueeze Inc. founders Robert Hyatt and Randy Hiebert, found that naturally occurring soil bacteria could form crystalline calcium carbonate that would readily attach to rock, cement, and steel to form a permanent bond. <https://biosqueeze.com/about>

Alchemy Geopolymer Solutions (AGS), an innovative concrete technology company that emerged from geopolymer research conducted at Louisiana Tech University, has won the inaugural LA StartUp Prize. <https://www.latech.edu/2014/09/30/green-concrete-technology-developed-at-louisiana-tech-earns-company-la-startup-prize/>

Terra CO2, a Golden, Colorado-based company that creates a low-carbon alternative to cement. A reactor, melts granite. Typical cement uses limestone, which releases CO2 when heated. Terra recently raised \$82 million in Series B funding. Terra CO2 uses widely available silicate-based raw materials which are among the most abundant materials on Earth. <https://terraco2.com/#>

A US government study of subsurface water-injection operations in the Bakken area of North Dakota showed that the maximum quantifiable risk that water from water injection wells would reach an underground source of drinking water was seven chances in 1 million well-years where casing and cement adequately covered the drinking-water aquifers. Where surface casings and cement do not cover the aquifer, the probability is six chances in one-thousand well years (Michle, 1991). The 1000-to-1 improvement is a testimony to the efficiency of the cement seal in a well.

Compliance with Standards and Best Practices

There have been collaborative efforts between oil and gas production companies and environmental advocacy groups that have recommended standards for incorporation in state regulations. To ensure the abandonment process is conducted in a standardized and effective manner, oil and gas operators follow a set of guidelines and best practices as outlined by several organizations:

API Recommended Practice RP 65-3 First Edition 2021: This standard provides guidelines for wellbore integrity during abandonment, including cementing procedures and requirements for testing the seals. It emphasizes the importance of selecting the right cementing materials and ensuring proper placement of cement plugs to prevent future fluid migration. This document provides guidance for the design, placement and verification of cement plugs used in wells that will be temporarily or permanently closed, as well as for well remediation and verification of annular barriers, reinforcing groundwater protection and emissions retention.

(<https://www.api.org/products-and-services/standards/important-standards-announcements/65-3>)

API Recommended Practice RP 10B: Recommended Practice for Testing Well Cements

API Spec 10-A: Specification for Cements and Materials for Well Cementing, Twenty Fifth Edition, Includes Addendum 1 (2019) and Addendum 2 (2022) API Specification 10-A, Includes Addendum 1 (2019) and Addendum 2 (2022)

Specification 10-A outlines requirements and recommendations for well cements, as well as their chemical and physical requirements, and procedures for physical testing.

National Petroleum Council Guidelines: The NPC's guidelines for well plugging emphasize the need for thorough planning, proper sealing techniques, and testing to ensure the long-term stability of abandoned wells. They also highlight the need for compliance with federal and state

regulations, which may vary depending on location. (https://www.npc.org/Prudent_Development-Topic_Papers/2-25_Well_Plugging_and_Abandonment_Paper.pdf)

Ground Water Protection Council (GWPC): Well Integrity Regulatory Elements for Consideration; Ground Water Protection Council (GWPC); January 2021; https://www.gwpc.org/wpcontent/uploads/2021/03/Well_Integrity_Elements_Revised_1_19_2021_002.pdf

Energy Workforce and Technology Council Best Practices: This document outlines the recommended procedures for orphan well plugging, focusing on areas such as stakeholder coordination, regulatory compliance, and advanced technologies for ensuring well integrity. It recommends the use of innovative approaches, such as downhole monitoring and imaging, to verify the integrity of well plugs. <https://www.energyworkforce.org/training-standards-best-practices/>

US Department of the Interior (DOI) Policies: The DOI has established specific guidelines for the abandonment of orphan wells on federal lands. These guidelines ensure that operators meet stringent environmental and safety standards, including the use of best practices for sealing and plugging wells.

Also: National Academies of Sciences, Engineering, and Medicine. 2024. **Practices and Standards for Plugging Orphaned and Abandoned Hydrocarbon Wells: Proceedings of a Workshop.** Washington, DC: The National Academies Press. <https://doi.org/10.17226/28035>

The National Academies convened an ad hoc committee of experts to provide advice to U.S. Department of the Interior (DOI) Orphaned Wells Program Office (OWPO) on regulatory, technical, scientific, and economic considerations for plugging and remediating orphaned and abandoned oil and gas wells. Project description <https://www.nationalacademies.org/our-work/technologies-and-practices-for-plugging-and-remediating-orphaned-and-abandoned-oil-and-gas-wells>

Read the Rules

However, the responsible regulatory agency (federal or state) has the final word. State rules come from the enabling legislation (which will be a little different state-to-state and federal agency-to-agency). The rules must follow the legislation and the existing rules and reporting requirements from previous related legislation. For states with some industry experience, the rules follow either industry recommended best practices or previous experience (what cement has worked, what groundwater aquifers to protect, what surface owners want to be left behind, etc.)

Rules will vary from state to state but all follow as close as practical to industry best practices. Larger differences occur between standards relating to onshore versus offshore wells. Operators will need to “read the rules” specific to each state or federal agency. These will differ in some degree based on legislation and on state experience.

Here is an example from Colorado (section 2 CCR 404-1-434 – Abandonment

<https://casetext.com/regulation/colorado-administrative-code/departments-400-department-of-natural-resources/division-404-oil-and-gas-conservation-commission/rule-2-ccr-404-1-practice-and-procedure/section-2-ccr-404-1-434-abandonment>).

For another example of state regulations on plugging here is Texas Railroad Commission Title 16 Part 1 Chapter 3 Rule 3.14

[https://texas-sos.appianportalsgov.com/rules-and-meetings?\\$locale=en_US&interface=VIEW_TAC_SUMMARY&queryAsDate=02%2F11%2F2025&recordId=157276](https://texas-sos.appianportalsgov.com/rules-and-meetings?$locale=en_US&interface=VIEW_TAC_SUMMARY&queryAsDate=02%2F11%2F2025&recordId=157276)

Use of Advanced Technology in Well Abandonment

There are a few plugging methods commonly in use today. Methods are dictated by the physical condition of the well, stability of the area, pressures, flowing liquids or gas (natural gas, hydrogen sulfide, CO₂), or equipment and material availability. Recent advancements in technology have made it possible to improve the efficiency and safety of well abandonment. But beware there is additional costs involved. These technologies include:

Downhole Cameras and Logging Tools: If well construction is unknown or there are indicators of well integrity problems, it may be necessary to utilize one or more electric or nuclear wireline logging tools to evaluate a well. These tools are used to inspect the condition of the wellbore and verify the integrity of the cement plugs. They allow operators to detect potential issues such as channeling during transition from liquid to solid with cement bonding or casing integrity, which can help prevent future leaks.

Real-Time Monitoring: Advanced sensors and real-time data transmission allow operators to monitor wellbore conditions continuously during the abandonment process. This can include temperature and pressure readings, which help ensure that cement is properly set and that no issues are detected in the wellbore.

Cement Bond Logging: Cement bond logs are used to assess the quality of the cement seal by measuring the bond between the casing and cement. This helps identify any voids or channels that could allow fluid migration. Cement bond logs (CBL) may be one of the most useful tools used to develop or modify a plugging plan and may be run with single, double, or a radial array receiver. The receiver configuration affects radial coverage of the survey. Bond logs may help with the interpretation of the quality of a cement bond to the casing and/or formation, identification of cement tops, spacers³⁸, and the presence of channelization, or micro annuli in the cement.

Regulatory and Environmental Considerations

Environmental concerns are a central consideration in well abandonment. Regulations often require operators to provide detailed abandonment plans, including measures for waste disposal and remediation of surface facilities and the surrounding land. The use of biodegradable fluids and responsible waste

management practices helps mitigate the environmental impact of well abandonment. Agencies like the Bureau of Land Management (BLM) and local environmental regulators monitor and enforce these standards.

As an example, here is a link to Colorado Rule 2 CCR 402-2-16 - STANDARDS FOR PLUGGING, SEALING, AND ABANDONING WELLS AND BOREHOLES

<https://casetext.com/regulation/colorado-administrative-code/department-400-department-of-natural-resources/division-402-division-of-water-resources/rule-2-ccr-402-2-rules-and-regulations-for-water-well-construction-pump-installation-cistern-installation-and-monitoring-and-observation-holewell-construction/rule-2-ccr-402-2-16-standards-for-plugging-sealing-and-abandoning-wells-and-boreholes>

The Concept of Permanence

A buyer of carbon offset credits will be concerned about the topic of permanence. The concept of something being permanent usually means lasting for a long time or maybe forever. When applied to oilfield practices it is difficult to ask an operator to plug an idle wellbore and have the result last forever. But for greenhouse gas emissions abatement from nature-based solutions like reforestation or from industrial processes like capping a well, some stakeholders would like for a permanent guarantee. Is that possible?

Two articles on permanence were released during COP29. A paper in **Nature** published by Myles Allen and two dozen other authors who helped develop the science of net-zero finds that climate “targets should acknowledge the need for **Geological Net Zero**,” whereby for each ton of CO₂ generated from fossil sources, one ton of CO₂ should be “permanently restored to the solid Earth.” Geological time scale storage is defined as “multi-century to millennial timescale.” (Ref. - Allen, M.R., Frame, D.J., Friedlingstein, P. et al. Geological Net Zero and the need for disaggregated accounting for carbon sinks. *Nature* (2024). <https://doi.org/10.1038/s41586-024-08326-8>)

From another perspective: “Offsets are not only allowable under the Paris Agreement—they are integral to how many countries achieve their climate targets”. New Zealand, for example, offsets over 25% of its emissions with forestry offsets through the NZ ETS. With the adoption of Article 6 to the Paris Agreement, which clarifies how countries can trade offsets internationally, the role of offsets is set to expand even further. This development opens the door for greater collaboration and the establishment of integrated global carbon markets - which will include forestry offsets and hopefully methane offsets from plugging orphan wells. The voluntary carbon market is also growing rapidly, reaching \$2 billion in 2021 and projected to hit \$50 billion annually by 2030.

COP29, held in Baku, Azerbaijan, made a major breakthrough in global climate action during its opening day. Nearly 200 governments agreed on a framework under Article 6.4 of the Paris Agreement. This deal sets up a UN-led global carbon market, allowing countries and companies to trade carbon credits more efficiently. The goal is to create a stronger demand for carbon credits, especially to fund climate projects in developing nations. <https://carboncredits.com/cop29-un-backed-global-carbon-market-takes-shape-article-6-4/>

How Long is Forever: Longevity of Cement in the Wellbore

Proper abandonment of idle oil wells is essential for preventing environmental contamination and for the safety of surrounding communities. Industry standards and practices ensure that this process is conducted safely and efficiently. Several key methods and protocols have been established to guide this process, as outlined in various reports and standards, including the API Recommended Practice (RP) 65-3, 1st Edition, Wellbore Plugging and Abandonment, the National Petroleum Council guidelines and others including state-specific and even country-specific guidelines.

The API (RP) 65-3 document provides guidance for the design, placement, and verification of cement plugs in wells to be temporarily or permanently abandoned, as well as remediation and verification of annular barriers. Wells temporarily abandoned (suspended) are intended to be re-entered or re-purposed in the future. The placement of barriers may depend on whether the well is to be temporarily or permanently abandoned.

Several studies on “re-purposing” an abandoned wellbore for energy storage or for use as a geothermal energy resource should be a step in an operator’s process of deciding on how to abandoned idle wells. In some cases, these applications will make sense but in most cases the orphan well will need to be plugged. See articles like the NREL study on Repurposing Inactive Oil and Gas Wells for Energy Storage: Maximizing the Potential Via Optimal Drivetrain Control by Sundeep et al, for more information on re-purposing idle wellbores. <https://docs.nrel.gov/docs/fy24osti/86579.pdf>

The longevity of cement in a wellbore is crucial to ensuring that abandoned wells do not pose future environmental risks. Cement is used to isolate the wellbore from the surrounding formations and prevent fluid or gas migration. The durability of cement depends on several factors:

Cement Composition: The type of cement used plays a significant role in its longevity. Common cement types used in well abandonment include Portland cement and specialized formulations that contain additives to enhance resistance to harsh downhole conditions, such as temperature and pressure extremes.

Sometimes a new technology is one that has existed but was previously unknown if they are allowed by state or federal rules. Examples of ‘new’ technologies may include plugging materials such as:

- o New blended cements (the manufacture process may reduce CO2 emissions such as a cement and biochar hybrid)
- o New cement additives that alter the chemical or physical properties of plugging materials
- o Bismuth and other alloy based plugging materials
- o Polymer based plugging materials

Environmental Conditions: The lifespan of cement can be affected by downhole conditions, such as temperature, pressure, and the presence of corrosive fluids. Cement can degrade over time if exposed to extreme temperatures, chemicals, or acidic environments. For instance, cement in wells with high concentrations of CO2 or H2S may degrade more quickly than in wells with more stable conditions.

Cement Shrinkage: Over time, cement may shrink due to the loss of water content, which can lead to voids in the wellbore. These voids can provide pathways for fluid migration, which compromises the integrity of the wellbore seal.

Mechanical Stress: Mechanical forces from the surrounding geological formations, such as tectonic movements or pressure changes, can cause cracks or fractures in the cement. These fractures may lead to gas or fluid leakage. Hydraulic fracturing of offset wells can sometimes be the cause of the mechanical stress leading to the failure of a cement plug.

On average, wellbore cement is designed to last for many decades, with some reports indicating it can maintain integrity for 30 years or more under ideal conditions. However, the cement's ability to maintain a seal depends largely on the environmental conditions and the quality of the cementing process. Proper cementing, along with regular monitoring, can help extend the lifespan of cement plugs. Project managers with significant field experience and those that take a quality control perspective on selecting, mixing and pouring cement can add an additional duration to the "permanence" of a well plugging operations.

In a Worst-Case Scenario, you can end up with Zombie Wells

Proximity of adjunct wells is also an important consideration, since operating within a field may cause formations to build pressure which may increase the potential to pressurize nearby wells. If formations begin to repressurize, old or poorly constructed wells may allow contaminants to migrate.

Each oil and gas well is supposed to get plugged at the end of its useful life. But there are some reported cases of "zombie" wells which is a well where the previous plugging operations has failed. But what happens when a well that has been previously plugged or just dormant for a long period of time starts to leak again? The term for this event is called a "**zombie well**." While there is no good process to identify how many of these wells exist and the evidence so far is that these wells are very unusual. There are some zombie wells that are making headlines today, especially in the Permian Basin in and around Fort Stockton in Pecos, Upton and Crane Counties, Texas.

Tubulars and bridge plugs will leak after 30-50 years because of microbiologically influenced corrosion. Temporary P&A and "improperly plugged wells" are those that mistakenly rely on steel as part of their barrier system; they are also the ones that spring back to life with brine geysers in the Permian Basin.

The major issue seems to be coming from increased underground pressure from the region's shale boom. When hydraulic fracturing is used to extract oil and gas, large quantities of produced water accompany the oil and gas production volumes. This salty 'wastewater' is either cleaned up and reused or is pumped back into the ground in wastewater injection wells. But if the wastewater is pumped too deep or at too high a pressure, it risks triggering man-made earthquakes (called induced seismicity). And if it's pumped too shallow, underground pressure increases, and poorly sealed wells start to leak again. This reinforces that point that wells need to be monitored past their plugging date to make sure the P&A job held back the subsurface pressure and methane emissions.

<https://www.texasmonthly.com/news-politics/lake-boehmer-dead-sea-west-texas/>

<https://oilprice.com/Energy/Crude-Oil/Zombie-Wells-A-280-Billion-Problem-the-US-Cant-Ignore.html>

But first, try to do what we know (cement) the right way.

Portland cement is one material the industry knows a lot about. Portland cement is the most common type of cement in general use around the world as a basic ingredient of concrete, mortar, stucco, and non-specialty grout. It was developed in England in the early 19th century by Joseph Aspdin, and is usually made from limestone. It is a fine powder, produced by heating limestone and clay minerals in a kiln to form clinker, and then grinding the clinker with the addition of around 5% gypsum.

In the oil and gas industry, securing the integrity of each well and protecting groundwater from contamination is a top priority. Cementing plays a pivotal role in achieving these goals, but not all cement is created equal. In fact, choosing the wrong type can lead to compromised well stability and costly operational issues. In this industry, cement must do more than just “hold things together”—it must withstand corrosive environments, resist shifting pressures, and form a “perfect” seal.

Properly made oil-well cement will have appropriate density and setting time, additionally with low consistency, and show resistance to settling and pumpability. When injected into the wellbore at specific temperature and pressure conditions, it quickly sets, hardens, and achieves mechanical strength. Once cured, the cement provides high impermeability, stability, and corrosion resistance.

A Different Challenge

But how often is the right cement used in the right way for plugging an orphan well? Traditionally, the top priority for cementing is to protect groundwater from contamination from wellbore fluids. But there is a different challenge from developing a barrier for water and hydrocarbon fluids than from a barrier designed to prevent the escape of methane molecules into the atmosphere.

Many studies show that a large percentage of wells have pressure behind pipe, often called SCP (sustained Casing Pressure) which provides a forcing mechanism for methane to escape. If we do all the steps the right way, we rarely see problems with cement plugs leaking. But we rarely do things the right way, we do it the fast or cheap way!!

There is often a lack of incentives to “go the extra mile” to plug an orphan well to a higher standard. After all it is a cost not a revenue stream. But doing things to a high standard should be rewarded by third party verification agencies for projects that achieve a stronger barrier in the wellbore for methane abatement. If your focus is on preventing methane emissions to be able to claim carbon offset credits, the project manager needs to focus on several important steps in the cementing process. For a barrier to a small molecule of methane, “good enough may not be good enough.”

To set a “high-bar” there are several key steps to pay close attention to:

- Pre-job performance testing of cement materials and additives:
- On-site water and cement slurry QC, calculations, and sampling;
- Place each plug on solid base and tag plugs to ensure correct position:
- Well diagnostics, plugging proposals, and on-site operations certified by a Professional Engineer

- On-site wait-on-cement (WOC) time measured for bottom plug from cured slurry sample:
- And most important of all, monitoring the well for a sufficient period-of-time after plugging to demonstrate that the well barrier to methane emissions will last

All this effort will not be cheap. And the temptation will be to just do enough to meet minimum requirements and pass inspection. Meeting these high standards may add several tens of thousands of dollars to the P&A job. After all no one wants to pay extra for a funeral. This end of a well life is not the most critical stage for most operators. But it is for those wanting to certify permanence in methane emissions abatement.

References:

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Kang M; Christian, S; Celia MA; Mauzerall, DL; Bill, M; Miller, AR; Chen, Y; Conrad, ME; Darrah, AH; Jackson, AR; "Identification and Characterization of high-methane emitting abandoned oil and gas wells"; *Proceedings of the National Academy of Sciences*, 2016 Nov; 29:113(48): 13636-41.

Conclusion

The abandonment of idle oil wells is a complex and critical process that requires adherence to established best practices, standards, and regulations. The primary method of abandonment involves plugging the well with cement and mechanical seals to prevent fluid migration. Following these guidelines, such as those set forth by the API, GWPA, National Petroleum Council, and Energy Workforce and Technology Council, ".ensures that wells are abandoned safely and in compliance with environmental regulations.

In answering questions about plugging idle wells, we have the problem of the lack of good data.

- It is rare for researchers to test the condition of a plugged well over an extended time period.
- When they do, they only test at or near the surface at the location of the well, and it is still possible to get a false negative because microbes may be metabolizing leaking methane in the soil before it reaches the surface. (Although, not reaching the surface may suffice for the purpose of buyers.)
- The leak is likely to be highly variable over time (like other kinds of leaks) and may diminish over decades.

Broadly speaking, there are three types of leaks: around 1 metric ton per year (t/y, a cow belches 0.064 t/y), around 100 t/y and above 10,000 t/y. The latter are major accident hazards and are caused by construction defects - large holes through the cement sheath. The other two represent the vast majority of P&A - and operating - wells. It is likely that only about 1 well in 50 leaks more than 1 t/y. Leaks in the first two categories rely on debonding at a cement interface and the formation of a micro-annulus. In particular, leaks of 1 t/y or less are probably happening as gas bubbles through a thin water layer.

The longevity of cement in wellbores is influenced by factors such as the composition of the cement, downhole conditions, and mechanical stress. With proper installation and monitoring, wellbore cement can last for several decades or more, ensuring that abandoned wells do not pose future environmental

risks. Mind that the majority of leaks from abandoned wells, at least those <50 years, are likely to come from the annuli, not the plug system. Operators find them in operating wells and fail to stop them. It's the interface between the cement plug and the "other" material that is always the weak point.

Current P&A standards are very good when it comes to preventing major accident hazards. Qualifying annular barriers and setting plugs reliably are well taken care of. However, the standards may be ill suited for preventing small natural gas leaks.

Proper well abandonment and the use of reliable cementing techniques are vital to protecting the environment, securing public safety, and minimizing long-term liabilities for oil and gas operators. These proven engineering best practices can also increase confidence in carbon offset credit buyers in the permanence of methane abatement field techniques. Monitoring plugged wells over an extended period of time would also help us to better understand permanence. Future studies of cement hybrids or cement substitutes to improve both the permanence and barrier-to-gas migration characteristics will help the industry's capabilities to ensure that plugging idle wells can be a significant addition to methane abatement.

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Jim Crompton retired from Chevron in 2013 after 37 years with the major international oil & gas company. After moving from Houston to Colorado Springs, Colorado, Jim established the Reflections Data Consulting LLC to continue his work in data management and analytics for Exploration and Production industry. From 2019 to 2023, Jim was a teaching faculty member and a Professor of Practice in the Petroleum Engineering Department lecturing on petroleum data analytics and the Digital Oilfield 2.0. He retired from active teaching in 2023 but still continues as a guest lecturer in several courses.

Jim was a Distinguished Lecturer for the Society of Petroleum Engineers in 2010-2011 speaking on the topic of “Putting the Focus on Data”. In 2024 he received a “Distinguished Member” award from the SPE. He is a frequent speaker at SPE conferences on digital/Intelligent Energy and the Data Foundation. His interests lie in the full spectrum of the information value chain from data capture, data management, data visualization, data access modeling and analytics, simulations, and serious gaming.

Jim graduated from the Colorado School of Mines (BS in Geophysical Engineering in 1974 and MS in Geophysics in 1976) before joining Chevron in Denver, Colorado. He later earned an MBA degree (1976) from Our Lady of the Lake University in San Antonio Texas.

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