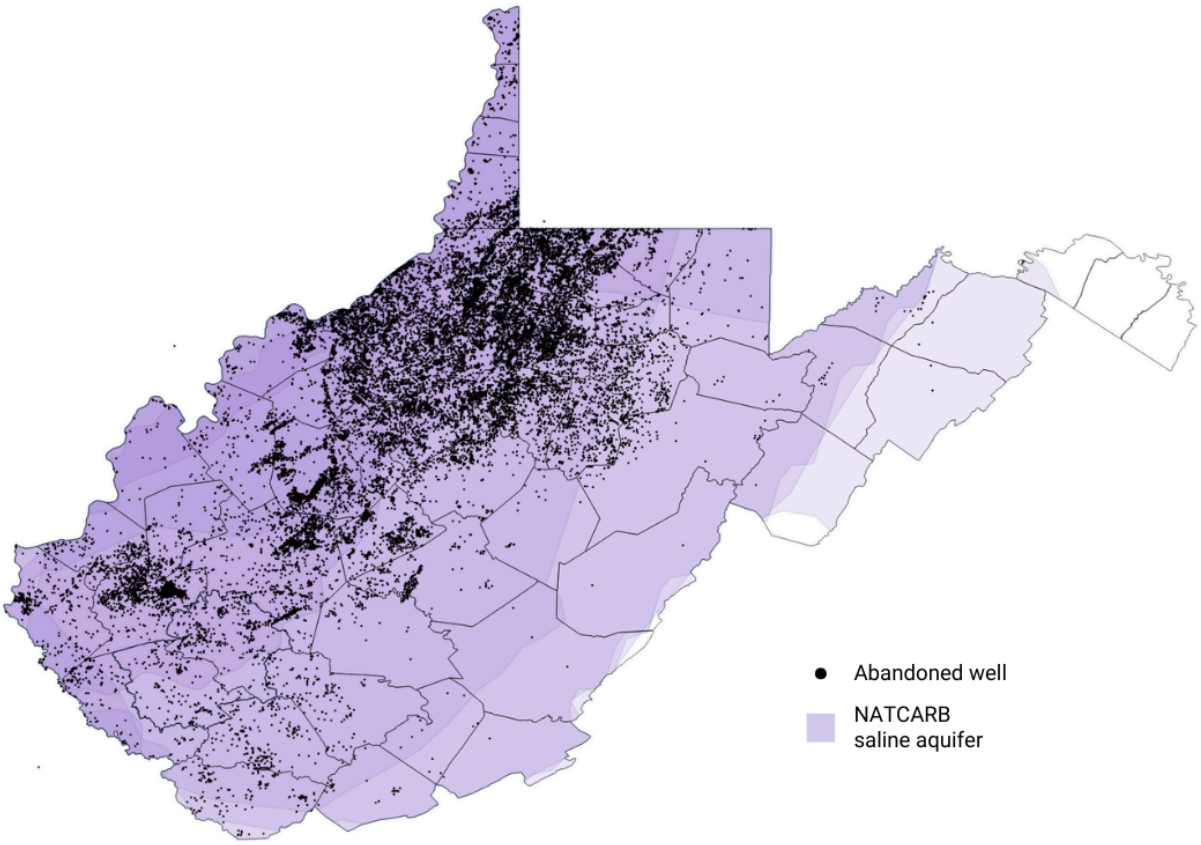
Ohio River Valley Institute

RESEARCH BRIEF

Abandoned Wells Could Wreak Havoc for Carbon Storage in West Virginia



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KEY TAKEAWAYS:

- Improperly plugged and unplugged abandoned wells provide pathways for escape for carbon dioxide (CO_2) stored via Class VI injection wells.
- West Virginia, slated to receive primary permitting authority over Class VI wells, is home to about 28,500 documented abandoned wells, nearly all of which overlie potential carbon storage locations. Researchers estimate there could be 400,000 additional undocumented abandoned wells across the state whose locations are unknown.
- Over 25,0000 nominally plugged wells may be improperly plugged and will need to be re-plugged. Even properly plugged wells can leak, since cement can deteriorate over time or corrode from long-term exposure to carbonic acid, which can form when CO_2 interacts with water.
- West Virginia's serial regulatory failures and its mismanagement of the Class II well program raises questions regarding the ability of state regulators to achieve the constant monitoring required to ensure the integrity of Class VI wells and to keep residents safe from any risks.

Despite the lack of large-scale commercial development to demonstrate its strategic value, carbon capture and storage (CCS) has been viewed as one way to meet greenhouse reduction targets. The US Department of Energy estimates that West Virginia has the potential to store 11.19 billion metric tons of carbon dioxide (CO_2) emissions in total saline storage, but these estimates likely far exceed realistic potential storage for commercial operations.

CLASS VI INJECTION WELLS

The EPA's Underground Injection Control (UIC) program consists of six classes of wells, the newest of which are Class VI wells, established in 2010 through the Safe Water Drinking Act (SWDA). Class VI injection wells are intended to store CO_2 deep underground for long-term geological sequestration, often in large deep saline reservoirs. Proposed sources of CO_2 include industrial facilities that produce things like steel or cement or from energy facilities such as coal-fired power plants.

As of 2018, there were more than 740,000 injection wells in the UIC program; however, only 24 Class VI wells have been permitted since the program was established in 2010: 6 in Illinois, 4 in California, and 2 in Indiana permitted by EPA and 8 in North Dakota and 4 in Wyoming permitted by state regulators. Four of the six permits issued by EPA in Illinois were associated with a project that was cancelled before any wells were constructed.[1] Few of these wells have injected CO_2 and "no Class VI wells have completed a full

[1] Angela C. Jones, "Class VI Carbon Sequestration Wells: Permitting and State Program Primacy", Congressional Research Service, April 16, 2024. Accessed on January 27th, 2025: https://crsreports.congress.gov/product/details?prodcode=R48033

permit lifecycle (i.e., through the injection phase and [Post-Injection Site Care] to site closure)".[2] In general, regulators and developers in the US have very little practical experience with CO_2 storage.

BASELINE RISKS ASSOCIATED WITH GEOLOGIC STORAGE

Even when best practices are followed, carbon storage is unpredictable and poses risks to nearby communities. The subsurface geologic formations where carbon would be stored are understudied and appear to be uncertain and dynamic. According to a review from the Institute for Energy Economics and Financial Analysis (IEEFA) of two of the world's oldest carbon storage projects in Norway, stored carbon dioxide can shift and migrate underground in ways scientists are still unable to predict. Even in the most carefully studied subsurface geologies in the world, researchers report previously unidentified storage formations, incidents of unintended carbon migration, and formations that unexpectedly rejected CO_2 storage.

What these projects demonstrate, IEEFA explains, is "that each CCS project has unique geology; that geologic storage performance for each site can change over time; and that a high-quality monitoring and engineering response is a constant, ongoing requirement." West Virginia's serial regulatory failures raise serious doubts about the state's ability to monitor these wells to the continuous and meticulous degree necessary to keep families safe, notwithstanding the hundreds of thousands of geologic variables posed by orphaned or unplugged wellshafts.

WEST VIRGINIA'S BID FOR PRIMACY

West Virginia is at the final stages of assuming primary enforcement authority or "primacy" of Class VI wells from the EPA, which it has for the other five classes of wells in the EPA's UIC programs. The EPA announced their proposal to grant state primacy to West Virginia in November 2024 and moved to approve this rule in January 2025. However, an executive action has suspended publishing in the Federal Register and the final rule has yet to be promulgated.

One reason states seek primacy is to expedite the Class VI application process. While EPA has since established an internal decision timeframe of two years, historically, these reviews have taken several years to complete. According to West Virginia's Class VI program description, state regulators intend to take between nine to twelve months to issue individual permits once the state receives primacy.

To obtain primacy status, states are required to adopt laws and regulation at least as stringent as EPA regulations. There are several reasons to be wary of West Virginia's ability to regulate Class VI wells, including the fact that its proposed program is less stringent than EPA's program, undermines the SDWA, and could exacerbate environmental justice issues in the state.

[2] US EPA., "EPA Class VI Permitting Report to Congress", US Environmental Protection Agency, October 28th, 2022. Accessed on January 27th, 2025: https://www.epa.gov/system/files/documents/2022-11/EPA%20Class%20VI%20Permitting%20Report%20to%20Congress.pdf

A recent report from the Natural Resources Defense Council examining West Virginia's UIC Class II program found that the state has inadequately regulated underground injection wells. Issues identified in this analysis included insufficient integrity tests of wells, lapsed permits, uncemented wells, and a pattern of unsafe practices and lax enforcement. A subsequent analysis conducted by Earthjustice on behalf of the Ohio River Valley Institute found that,

> *Data from EJScreen suggest that all Class II injection wells the NRDC Report found to have compliance issues are located next to communities with environmental justice concerns. Most of the wells are sited in communities where water systems received a high number of [Safe Drinking Water Act]violations that were not returned to compliance. Most were also sited in low-income communities, and nearly all of the communities nearby the wells are identified as "disadvantaged communities" according to the Justice 40 and EPA IRA tools.*

EXISTING OIL AND GAS WELLS POSE RISKS TO GEOLOGIC STORAGE PROJECTS

Another potential hazard is the large number of unplugged and improperly plugged abandoned wells in the state that provide a pathway for injected CO_2 to leak into groundwater or escape into the atmosphere. If stored CO_2 escapes from the subsurface it can also lead to blow-outs, which can pose serious risks to nearby communities. In 2020, a pipeline carrying pressurized CO2 suddenly burst outside of Satartia, Mississippi, releasing a cloud of toxic CO2 gas into the nearby community. This incident resulted in dozens of hospitalizations and hundreds of evacuations. Since "supercritical" CO_2, compressed into a gaseous liquid,[3] is under very high pressure when stored, the likelihood of leakage from poorly plugged or abandoned wells is high.

The potential for long-term or "permanent" sequestration of supercritical carbon dioxide fluid (CO_2) injected into geological formations from Class VI injection wells in West Virginia could be significantly undermined by the plethora of abandoned wells scattered across the state. EPA describes these wells and other "man-made structures… which provide a flow path out of the injection zone" as artificial penetrations.[4] Improperly plugged or unplugged abandoned wells and other artificial penetrations can serve as vertical conduits for injected CO_2 and brine from Class VI wells that could pollute drinking water and damage public health.[5] Carbonic acid, which forms when CO_2 interacts with water, can even degrade properly plugged wells, allowing CO_2 to migrate and impact drinking water.[6]

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[3] National Energy Technology Laboratory (NETL), "Carbon Storage FAQs," US Department of Energy, Accessed January 2025, https://netl.doe.gov/carbon-management/carbon-storage/faqs/carbon-storage-faqs#:~:text=Carbon%20dioxide%20(CO2)%20can,the%20temperatures%20and%20pressures%20present.

[4] US EPA, "Underground Injection Control (UIC) Program Class VI Well Area of Review Evaluation and Corrective Action Guidance", United States Environmental Protection Agency, May 2013. Accessed January 2025: https://www.epa.gov/sites/default/files/2015-07/documents/epa816r13005.pdf

[5] Dominic DiGiulio, "Understanding, Evaluating, and Remediating Leakage from Abandoned Oil and Gas Wells During Geological Storage of Carbon Dioxide," *Center for Applied Environmental Science*, March 18, 2024. Accessed on December 25, 2024: https://environmentalintegrity.org/wp-content/uploads/2024/03/20240318_DiGiulio_report_Final.pdf

[6] S. Taku Ide et al., "CO_2 leakage through existing wells: current technology and regulations," January 2006. Accessed on December 25, 2024: https://sequestration.mit.edu/pdf/GHGT8_Ide.pdf#:~:text=Although%20current%20well%20closure%20and%20abandonme

ORPHANED AND ABANDONED GAS WELLS

The vast number of undocumented wells in the state could also make monitoring difficult and further increase the potential for cross migration between aquifers leading to a migration of injected fluids. The recent revelation that the operator of the first-ever CO_2 well permitted by EPA found 24 previously unidentified wells near its storage project underscores the threat posed by these artificial penetrations, especially in a state with as robust a history of oil and gas extraction as West Virginia.[7]

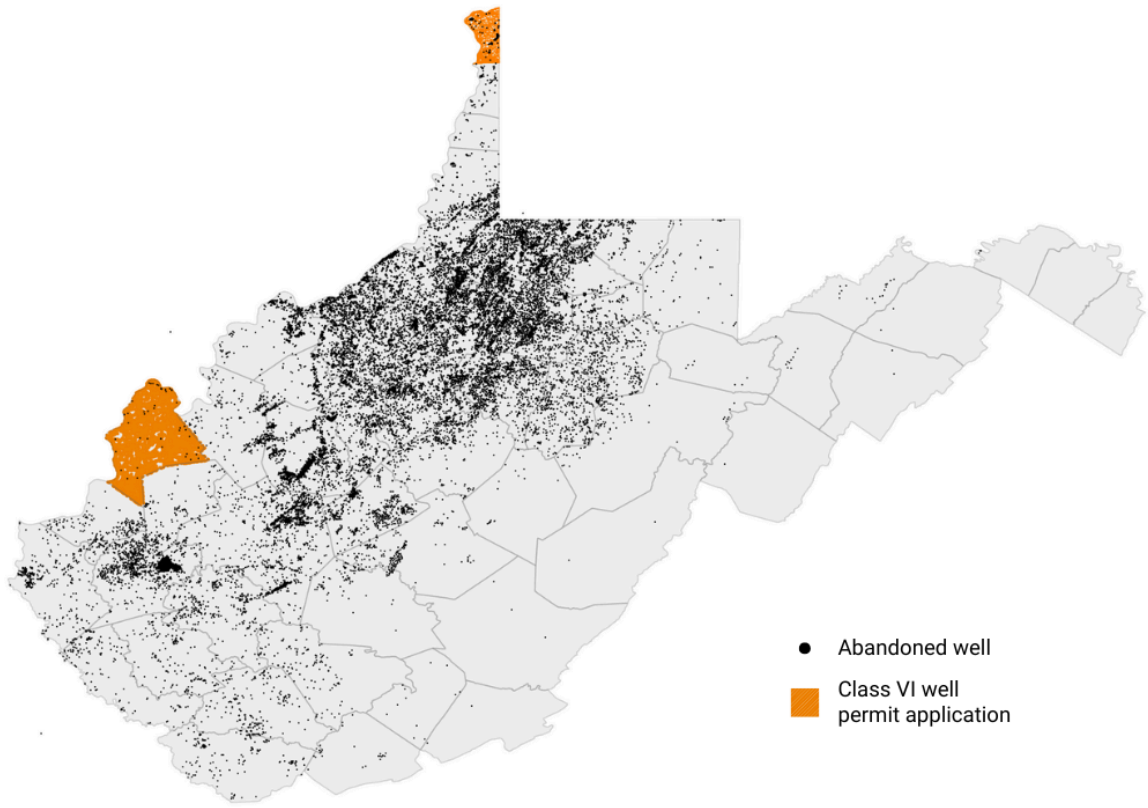
The question will likely be how much leakage is detected, how much is deemed acceptable, and how it will be managed. While EPA's guidance recommends several methods for finding undocumented and abandoned wells, West Virginia's application does not identify how they would accomplish this task. It is imperative that these wells are not only properly plugged to ensure the integrity of the carbon stored in Class VI wells, but that proper monitoring is in place in perpetuity.

Unfortunately, West Virginia's record of monitoring plugged and unplugged abandoned wells isn't reassuring. The state currently has just 17 field oil and gas well inspectors or one inspector for every 5,100 unplugged documented wells in the state. To ensure safety and compliance, the costs to properly implement CCS could be prohibitive given the vast number of abandoned wells in the state.

nt%20technology,plugging%2C%20overpressure%2C%20corrosion%2C%20and%20other%20failure%20conditions.&text=Wells%20plugged%20after%201952%20are%20the%20least,and%20the%20due%20diligence%20required%20by%20regulation.

[7] Annie Snider, "ADM finds 24 other wells near its leaky Illinois carbon sequestration site," *E&E News (Politico),* November 5, 2024. Accessed on December 25, 2024: https://www.eenews.net/articles/adm-finds-24-other-wells-near-its-leaky-illinois-carbon-sequestration-site/

Map 1: Abandoned wells and West Virginia counties that have applied for Class VI well permits



Source: Ohio River Valley Institute

DOCUMENTED AND UNDOCUMENTED WELLS

It is unknown how many wells have been drilled in West Virginia. It wasn't until 1929 that the state began requiring permits for the drilling of oil and natural gas wells.[8] The West Virginia Geological Survey (WVGES) has location data for 174,795 wells in the state, some of which were not drilled, including 157,698 with owner and completion records.[9] According to the Upstream database of state records, there are approximately 113,550 documented drilled wells (active, abandoned, inactive, orphan, plugged, shut-in, dry hole, injection) in West Virginia. This includes about 28,500 documented unplugged abandoned wells (orphaned, inactive, shut-in, dry hole, injection) in the state.

A 2018 study by scholars at Princeton University estimated West Virginia has anywhere from 63,080 to 759,343 unplugged abandoned wells, with their best estimate being 440,000 abandoned wells in the

[8] West Virginia Legislative Auditor (Performance Evaluation & Research Division), "Agency Review: Office of Oil and Gas, Department of Environmental Protection," September 2012 (PE 12-10-532). Accessed on December 25, 2024: https://www.wvlegislature.gov/legisdocs/reports/perd/Oilgas_9_2012.pdf

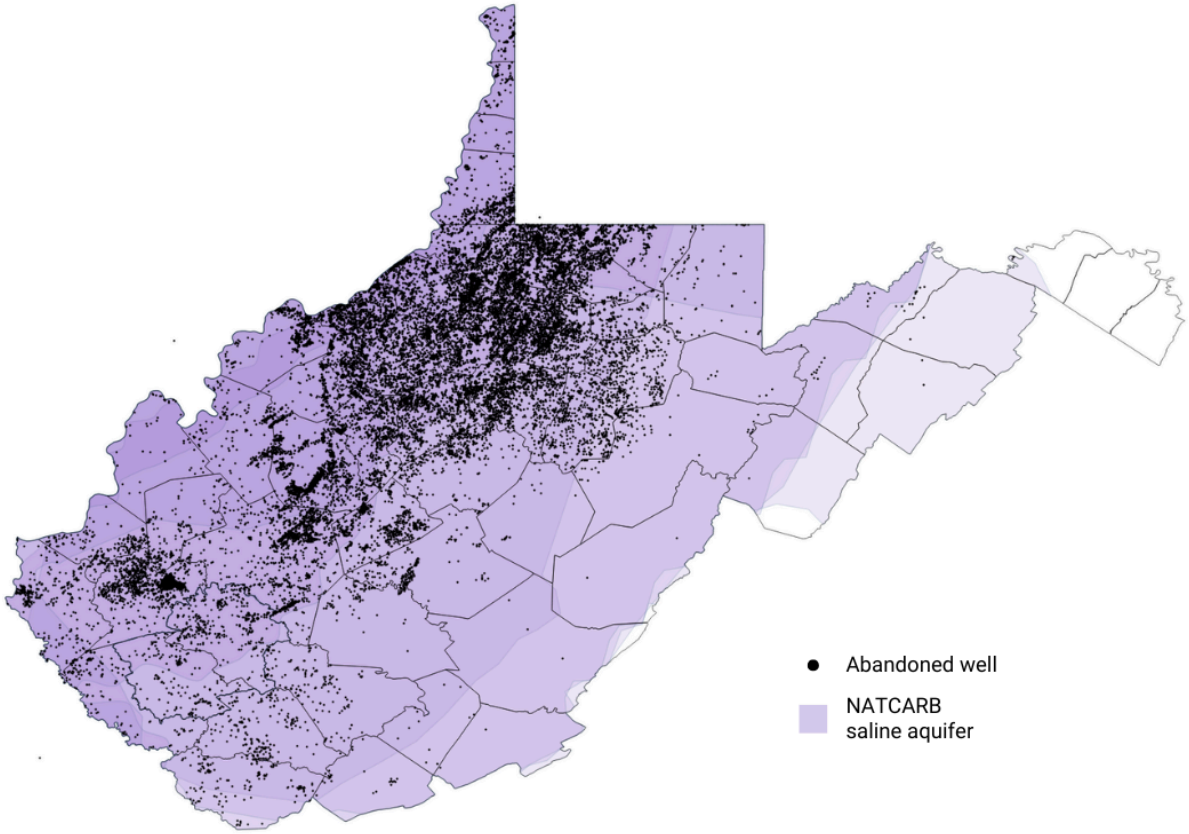
[9] West Virginia Geological & Economic Survey. Accessed on December 25, 2024: https://www.wvgs.wvnet.edu/pipe2/stats/tblcnts/tablecountsmain.aspx

state.[10] The West Virginia Department of Environmental Protection (WVDEP) estimates 9,000 undocumented orphaned wells in the state, but as the research above notes this is very likely an underestimate.[11]

Recently, the state received $25 million in federal well plugging grants from the Infrastructure Investment and Jobs Act which allowed contractors to plug documented orphaned wells and any undocumented wells they found throughout 8 regions. Of the approximately 200 wells plugged, more than a quarter of the plugged wells were "undocumented" orphaned wells, which highlights how pervasive undocumented wells are in the state.

The map below shows the documented abandoned wells across the state. Almost all the abandoned wells overlie prospective CCS formations.

Map 2: Documented abandoned wells and potential carbon storage formations



Source: Ohio River Valley Institute

[10] Stuart Riddick et al., "Measuring methane emissions from abandoned and active oil and gas wells in West Virginia," Science of The Total Environment 651, October 9, 2018. Accessed on December 25, 2024: https://www.sciencedirect.com/science/article/abs/pii/S0048969718339561?via%3Dihub

[11] Interstate Oil & Gas Compact Commission, "Idle and Orphaned Oil and Gas Wells: State and Provincial Regulatory Strategies," 2021, page 28. Accessed on December 25, 2024: https://oklahoma.gov/content/dam/ok/en/iogcc/documents/publications/iogcc_idle_and_orphan_wells_2021_final_web.pdf

PLUGGED AND IMPROPERLY PLUGGED WELLS

A large portion of the plugged wells in the state pre-date modern plugging standards that help prevent fluid migration and water contamination. West Virginia passed the Abandoned Well Act in 1994, which made significant changes to the regulation of abandoned wells. The legislature found that "plugging requirements for certain older oil and gas and other wells may not have been sufficient to protect the underground water supplies to prevent the movement of fluids between geologic horizons" and that "[m]any wells may exist in West Virginia which are abandoned and either not plugged or not properly plugged in a manner to protect underground water supplies [or], to prevent the movement of fluids between geologic horizons."[12] The West Virginia Department of Environmental Protection noted in 1997 that 90 percent of its $3.1 million in plugging expenditures since 1993 were "spent to re-plug improperly plugged wells."[13]

WELL PLUGGING STANDARDS

State laws regarding well plugging were not put into place until 1929, the same year that the state began requiring permits for the drilling of oil and gas wells.[14] While the state's plugging standards included the use of cement by 1929, it wasn't until 1953 when the American Petroleum Institute began recommending hydraulic grade Portland cement for well plugs and casing.[15] Prior to the early 1950s, the cement plugs used were often contaminated with mud and failed to harden into effective seals to protect against leaks. This cement often lacked sufficient additives for proper cement setting.

It wasn't until 1964 that the state specified the use of "hydraulic cement" as a well plugging material. The first mention of using hydraulic cements "as recognized by the American Petroleum Institute" was first established in 1974 in state regulations. In 1993, state regulations specified the use of API "Class A Ordinary Portland cement." Many scholars and experts of well plugging maintain that modern plugging standards were not adopted until the 1970s when federal environmental laws began protecting groundwater supplies.[16]

While state regulations have been updated regarding the intervals to be cemented to protect fresh water zones and material used for multiple cement plugs and other requirements, West Virginia regulators are not required to inspect orphan and abandoned wells after they are plugged. Placement of cement plugs also does not require an inspector to be present, just a written affidavit. West Virginia also does not

[12] West Virginia Legislature, H.B. 4065, March 30, 1994. Accessed on December 25, 2024: https://www.wvlegislature.gov/Bill_Text_HTML/1994_SESSIONS/RS/signed_bills/house/HB4065%20ENR_signed.pdf
[13] West Virginia Environmental Protection, "Enviro Facts: Plugging Oil and Gas Wells," 1997. Accessed on December 25, 2024: https://dep.wv.gov/pio/Documents/Enviro_Fact_Sheets/Plugging Wells.pdf
[14] Acts of the Legislature of West Virginia, Regular and Extended Session, 1929, page 319. Accessed on December 25, 2024: https://www.wvlegislature.gov/legisdocs/publications/acts/Acts_1929.pdf
[15] The National Petroleum Council, "Plugging and Abandonment of Oil and Gas Wells," Paper #2-25, September 15, 2011. Accessed on December 25, 2024: https://www.npc.org/Prudent_Development-Topic_Papers/2-25_Well_Plugging_and_Abandonment_Paper.pdf
[16] Ibid

require mechanical integrity testing prior to well plugging to ensure the structural soundness of the wellbore. Federal guidelines require mechanical integrity testing for Class VI wells but storage projects could be jeopardized by migration of CO_2 through other wells not constructed to this standard. Once a well is plugged, the state does not (in general) inspect or monitor plugged wells. Well barrier and well integrity failures are not always addressed though well plugging.

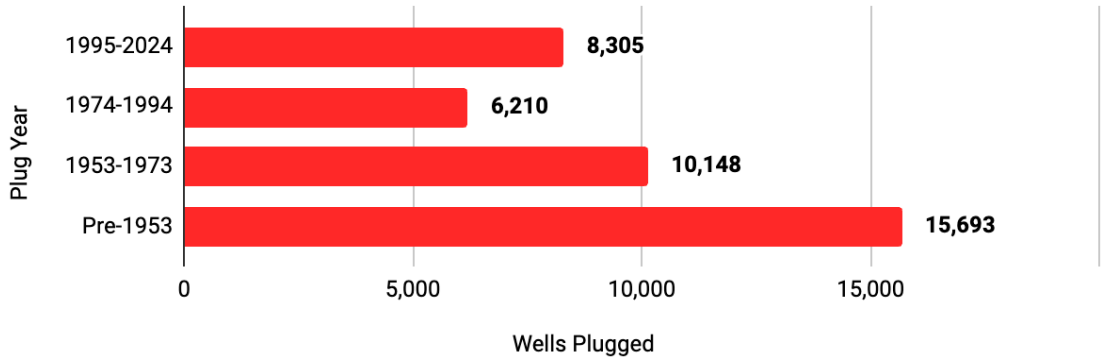
Even if a well is plugged to modern standards, the typical lifespan of a plugged well is largely unknown. What is known is that Portland cement can shrink and crack over time and cause leaks into adjacent zones. Plugged wells can also experience casing failure, especially in older wells. A 1989 report by the Government Accountability Office (GAO) estimated that out of the 1.2 million abandoned wells in the United States, (at that time) "about 200,000 may not be properly plugged."[17] Engineer and former US Environmental Protection Agency employee Daniel Arthur has estimated that as many as 500,000 plugged abandoned oil and gas may be leaking.[18] The aforementioned study by Princeton scholars included methane measurements of 338 well sites in West Virginia, including 112 plugged wells. The scientists found that 21 of the plugged wells, nearly a fifth, were leaking methane. A more recent study conducted in western Pennsylvania found that a third of the plugged wells examined were leaking gas through vent pipes at the surface while 10 percent of plugged wells were leaking gas through soil at the surface. It is also important to note that production casing in Class VI injection wells are cemented from the bottom to the top but this is not true of oil and gas wells. This means there is a possible pathway into which stored CO_2 could escape from any oil and gas well near an injection site.

MOST WELLS PLUGGED BEFORE MODERN WELL PLUGGING STANDARDS

According to the West Virginia Geological and Economic Survey (WVGES), there are records for 40,361 oil and gas wells that have been plugged. Approximately 39 percent of the plugged wells in West Virginia were plugged before 1953 while nearly two-thirds (64%) of the wells plugged in West Virginia were plugged before state regulations specifically mentioned API cement standards in their state regulations on plugging wells. [19] Only about 21 percent of the plugged wells in the state were plugged after passage of the Abandoned Well Act in 1994, which made improvements to the regulation of abandoned wells.

[17] General Accounting Office, "Drinking Water: Safeguards Are Not Preventing Contamination from Injected Oi and Gas Wastes," July 1989. Accessed on December 29, 2024: https://www.gao.gov/assets/rced-89-97.pdf
[18] Amanda Drane, "Zombie Wells, Part 1: Texas oil wells are leaking toxic waste, and no one wants to pay to clean it," *Houston Chronicle*, July 22, 2023. Accessed on December 29, 2024: https://www.houstonchronicle.com/business/energy/article/zombie-wells-toxic-waste-taxpayer-cost-18001336.php
[19] West Virginia Administrative Regulations, Department of Mines, Chapter 22-4, Series IV 1973. Accessed on December 29, 2024: https://apps.sos.wv.gov/adlaw/csr/ruleview.aspx?document=6567 Note: In 1964 state rules for plugging included "hydraulic cement" for the first time but it wasn't until 1974 API recognized cement was included in standards.

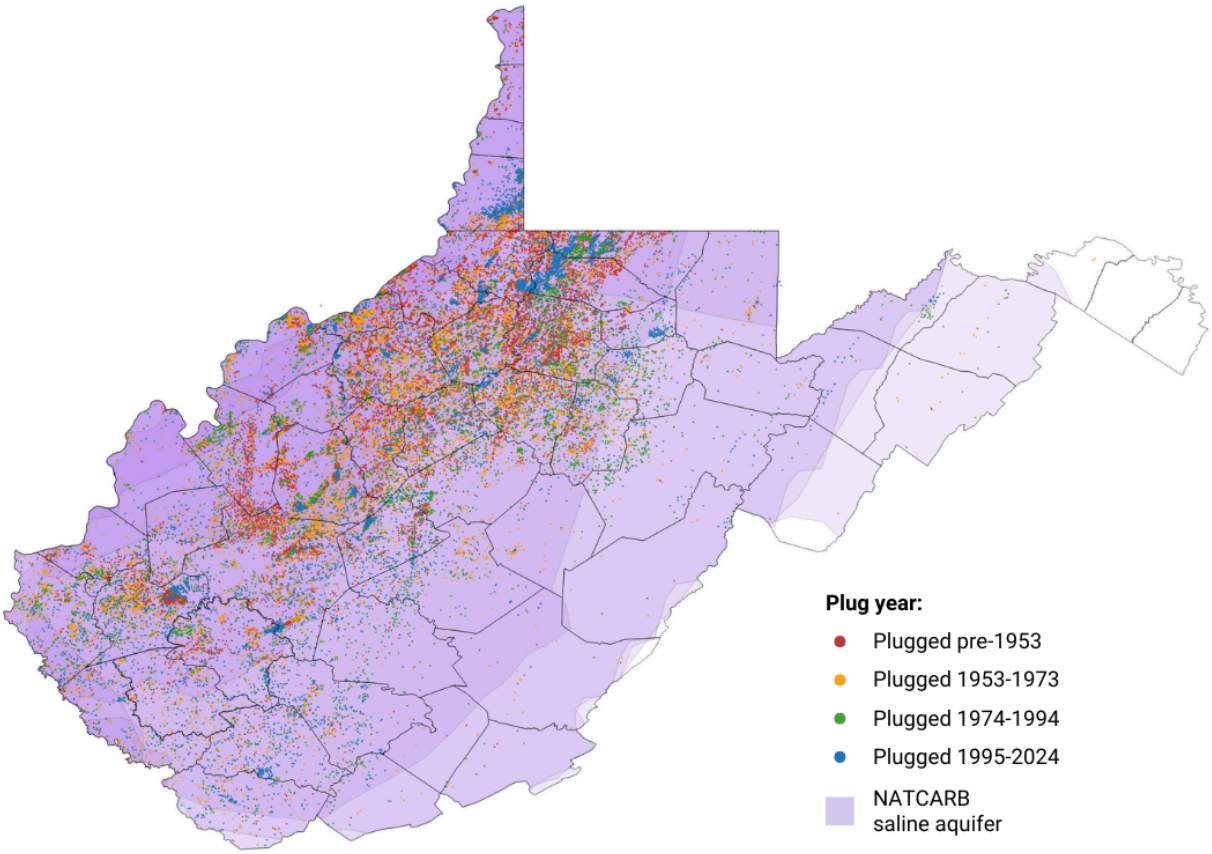
Figure 1: Plugged Wells by Age in West Virginia



Source: ORVI analysis of WVGES plugged wells data. 14 of the wells had an unknown plugging year.

The map below shows the more than 40,000 plugged wells in the state, with most wells concentrated in the northwestern and northcentral part of the state where most of the drilling has taken place. Almost all of the plugged wells overlay the potential storage areas for Class VI injections wells.

Map 3: Plugged wells by plug year and potential carbon storage formations

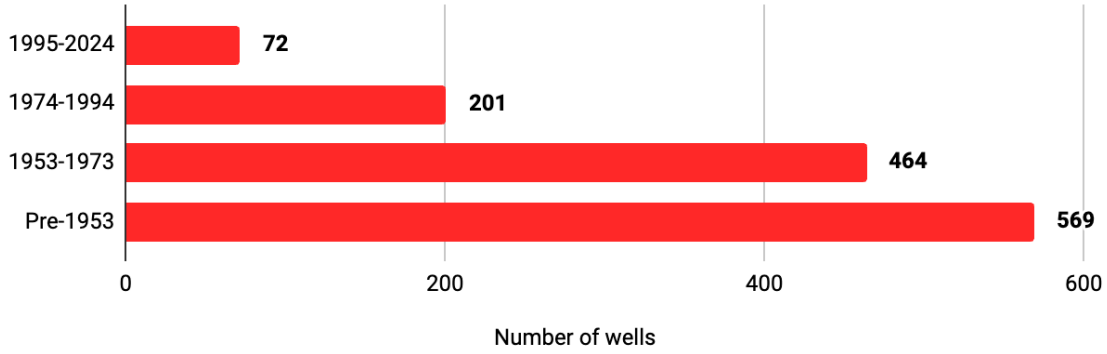


Source: Ohio River Valley Institute

RE-PLUGGED WELLS IN WEST VIRGINIA

More than 1,300 of the wells plugged in West Virginia have been plugged more than once. According to WVGES data, 69 percent (1,033) of the wells that have been plugged more than once were initially plugged before 1974. Approximately 569 wells that were plugged at least twice were plugged initially before 1953. Many of these re-plugged wells may have been in coal mining areas of the state where new federal regulations required specific plugging methods in mining areas. Nevertheless, these wells are only a portion of all plugged wells in the state, highlighting that many older plugged wells were not plugged properly because modern plugging standards did not exist. As previously mentioned, the WV DEP spent $2.8 million over a five year period in the 1990s re-plugging plugged wells.

Figure 2: Initial Year Plugged, Wells that were Plugged Twice



Source: ORVI analysis of WVGES plugged wells data. 14 of the wells had an unknown plugging year.

CONCLUSION

Improperly plugged and unplugged abandoned wells pose a significant obstacle to the storage of CO_2 from Class VI injection wells since they provide a leakage pathway for CO_2 into groundwater and the atmosphere. Plugged wells can and do leak, and it is unknown how many undocumented wells exist in the state. West Virginia regulators will need to provide a robust evaluation of plugged and unplugged abandoned wells and constant, high-quality monitoring to ensure that groundwater resources and public health are protected from the risks associated with the long-term storage of CO_2, risks that are exacerbated by West Virginia's serial regulatory failures and the legacy of the historic and current oil and gas industries.