Underground Oil Storage in Texas

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A report responding to changes to Statewide Rule 95 permitting oil storage in underground formations other than salt caverns.

Written by: Jess Cohen, Ben Delhees, Diane Li, Melissa Stok
MIT Environmental Solutions Initiative Rapid Response Group

Advised by: Emma Pabst
Environment Texas Research and Policy Center

Abstract

COVID-19 shutdowns in the first few months of 2020 caused a severe drop in fuel demand and prices. In order to alleviate the economic burdens placed on the oil and gas industry, the Railroad Commission of Texas passed a temporary exemption in May 2020 that expands the potential options for storing oil underground. The following report explores conventional underground oil storage in salt caverns as well as alternative options and potential risks to human and environmental health. We also provide a summary of the permitting process for storage sites, highlighting periods for public involvement.

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Deregulation in Response to COVID-19

As a consequence of widespread COVID-19 shutdowns, there has been a dramatic decrease in global demand for oil to fuel transportation. In late April 2020, oil prices fell into the negatives for the first time in global history, indicating excess supply and an urgent need for more storage capacity.[1]

The Railroad Commission of Texas (RRC) is the state agency that regulates Texas' oil and gas industry – an industry that produces 41% of the nation's oil.[2] The RRC sought to alleviate the economic burdens facing Texas' oil industry first by considering limiting the volume of oil and gas that operators could produce. However, the RRC ultimately decided instead to issue temporary exceptions to statewide rules, claiming that companies were already reducing production of their own accord.[3] These temporary exceptions passed on May 5, 2020 as emergency measures to help reduce the economic burdens on oil and gas companies caused by COVID-19.

The first of the two temporary exemptions waives filing fees for a number of permits required under Statewide Rule 78 to inject fluids, hydrocarbons, and associated wastes into underground formations.[4] This is effective until the end of 2020 unless the RRC finds it fit to either extend or retract the rule.

The second temporary exemption to Statewide Rule 95 extends permission for oil storage to "a geological formation other than an underground salt formation." [5] Applications for these less conventional storage sites may be submitted anytime within the next year, and any oil stored there must be removed within five years. These time frames could change if the RRC finds it necessary to extend or annul the rule. Additionally, this exception suspends Rule 95's public hearing requirement, where members of the public and other impacted stakeholders can officially comment and state any objections or approvals they have on the project. This requirement suspension means that it is no longer mandatory to hold a public hearing for underground storage sites unless the project is protested. However, the RRC maintains that applicants are "required to demonstrate that the proposed storage facility will be created, operated, and maintained in a manner that will prevent waste of stored crude oil, uncontrolled escape of crude oil, pollution of subsurface water, and danger to life or property."

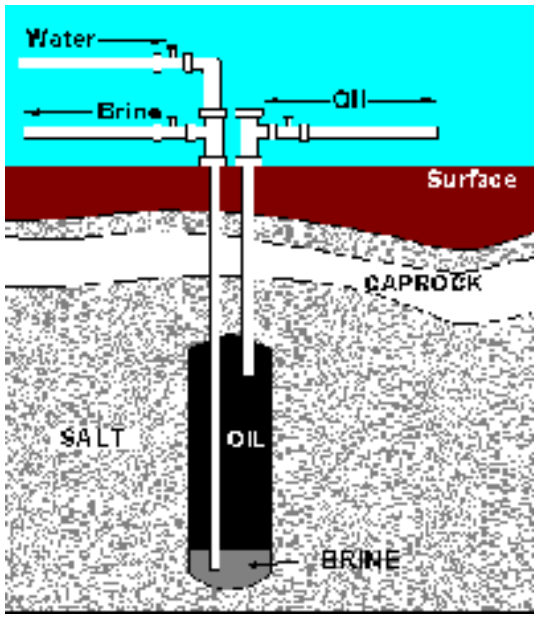
Oil Storage in Salt Caverns

Oil stored underground in geological formations is most commonly kept in salt caverns. Salt caverns are engineered from naturally occurring salt domes* by solution mining.[6] Water is pumped into the formation to dissolve the salt. When the brine is pumped out, the vacant space can be filled with oil.

Oil storage in these salt caverns is particularly attractive when compared to other underground geological formations because they are naturally well-sealed and engineered for rapid injection and extraction of oil. Salt, which lines the top and sides of these caverns, has very low permeability for oil. Cracks that might form in the cavern lining also close rapidly due to the pressure 2000-4000 feet underground where these caverns exist.

The layered combination of oil on top of water that fills the caverns provides the mechanism for adding and removing oil to and from storage. By pumping water out of the cavern, oil can flow in; by pumping water into the cavern, oil is displaced to the surface. For frequent injection and extraction cycles, a brine pond needs to be maintained at the surface. Pumping freshwater into the cavern to extract oil can only be done a limited number of times because each cycle dissolves more salt and expands the size of the cavern.[7]

The U.S. Department of Energy (DOE) maintains the world's largest emergency supply of crude oil in the Strategic Petroleum Reserve (SPR).[9] This series of salt caverns, divided into four sites along the Gulf Coast, can store up to 714 million barrels of oil.[10] Two of the four sites, Big Hill and Bryan Mound, are located in Texas. In late April, the DOE leased 23 million barrels of the 77 million barrels of remaining free space in the SPR to nine companies.[11]



Cross section of a salt cavern [8]

Mined Rock Caverns

Besides salt caverns, mined rock caverns have also been used for underground oil storage.[12] Caverns can be lined with thin sheets of stainless steel to seal in the oil. Alternatively, unlined caverns can employ hydrodynamic containment. Fractures in the surrounding rock are filled naturally or artificially by pressurized water which prevents oil from leaking out of the cavern. Although shallower than salt caverns, mined rock caverns tend to be more expensive to develop because they require underground work whereas salt caverns can be created and operated entirely from the surface.

Note: In response to an email from Environment Texas Research and Policy Center, the RRC clarified that the temporary exemption to Statewide Rule 95 was only intended to apply to depleted reservoirs.[13] The structure and concerns of storing oil in depleted fields will be discussed in the next three sections on porous formations, failure modes, and site analysis.

Oil Storage in Porous Formations

In the absence of caverns, oil can also be stored in porous sedimentary rock formations. This can be imagined as storing liquid in a brick as opposed to a bowl. It is less economically favorable because storage capacity is lower in any given volume and injection and extraction are slower.

Identifying Options

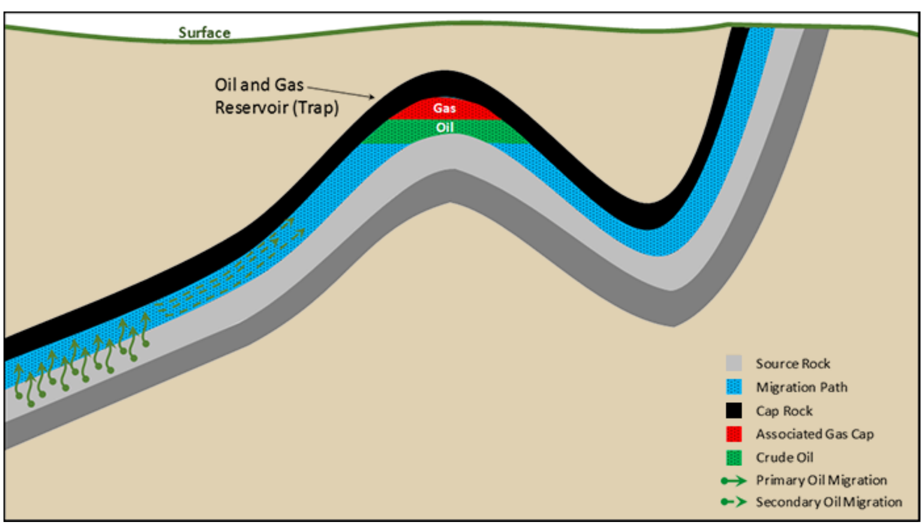
Porous formations might include depleted oil and gas fields or deep saline aquifers*. Both are found at greater depths than freshwater aquifers and should include both a reservoir rock and a cap rock. The reservoir rock, which holds the oil, should have relatively high effective porosity* (connected pore volume) and permeability* (rate of fluid flow through the rock).[14] The cap rock, which contains the oil from above and on all sides, should have low permeability to oil and no fault lines through which oil can leak and escape into groundwater sources above.[15] The public should be wary of any proposals for shallow underground oil storage in porous rock layers as these may not be properly sealed from drinking water sources.

Geologists identify these underground formations through a combination of aerial and space image analysis, field visits, seismic surveys, and core samples*.[16] This allows them to map depths, thicknesses, faults and folds of layered rock strata. The physical and mechanical properties of the rock samples are used in mathematical models to determine acceptable fluid pressures in the formations to avoid leakages. This entire process can often take multiple years from start to finish. However, the oil and gas industry may already possess much of this data from previous exploration for productive fields.

Depleted Oil Fields/Wells

Depleted oil wells have been identified as a potential area in which excess crude oil* can be stored. These are already widely used for natural gas* storage across the United States.[17] Since these formations have previously held oil for many years, using them to do so once again could help relieve the burdens of the oil storage crisis. In order to properly understand the advantages and the risks of using these for storage, it is first important to know more about these formations.

Hydrocarbon reservoirs are associated with sedimentary rock formations.[18] The rock is made of layers that are initially horizontal, formed by the deposition of sediments from water. These layers are then deformed by tectonic forces after the initial deposition and solidification.



Cross section of rock layers in a typical oil and gas reservoir [19]

Conventional hydrocarbon* reservoirs have specific geological requirements for them to trap oil and gas in a contained area. Various layers of rock with different porosities and permeabilities need to be layered and folded in a specific way. The base layer is a source rock layer which contains the original organic material that was converted into hydrocarbons. The layer above is a water-filled rock with high porosity and permeability. Water, oil, and gas exist in the pore space between the grains of the rock. The top layer is a cap rock which is impermeable to flow to prevent oil and gas from going all the way to the surface. Hydrocarbons in the source rock migrate upwards into the rock layer above and are trapped there because of the cap rock.

Another important factor is the folding of the rock layers. There are various formations that will form a trap which is capable of stopping the migration process and keeping oil and gas in place over geologic time. Some of these are stratigraphic traps*, where oil and gas can be confined because of porosity and permeability changes in the rock layers. Structural traps*, which comprise the second type of trap, are geological traps that form because of changes in the subsurface caused by tectonic, gravitational, diapiric*, and compactional processes.[20] They are characterized by a bend or dip in the rock layers. Anticlines* are structural traps with strata bent into an arch-like shape. They are the most common oil-storing formation. In each of these formations, oil migrates upwards through the migration layer because of its lower density than water. Once it reaches the highest point in the anticline or other trap, it stays there over geologic time. When drilling for oil, companies drill into those pockets of oil below the surface in order to extract it.

Once oil wells are depleted, wells are plugged using cement that is placed into the bore hole to prevent migration of fluids.[21] The infrastructure and space is already present as a place for oil storage to occur, which is why these have been identified as a potential location for storage of the excess oil in Texas.

Oil can be injected into the depleted wells and be left for extraction once there is demand for it on the market. This is not economically ideal–it is best to simply leave the oil in the ground in the first place rather than extract, reinject, and extract once again. However, with wells that are already drilled and producing oil, companies may be hesitant to slow down their drilling. The US EIA has determined that the average cost range for the entire searching, drilling, and extraction process for oil wells is between \$4.9 and \$8.3 million.[22] Since oil companies have fixed costs they have to cover and they could lose land leases to competitors, economics often supports running wells at a loss for a period of time. After shutting-in* a well (temporarily stopping pumping) companies must also invest additional funds in order to get the well to produce oil at the same level again.[23] The costs associated with slowing or stopping extraction push operators to prefer storage over alternative options.

The risks associated with storing oil in depleted oil wells will be further addressed in the next section, along with establishing the importance of proper studies and evaluations for each well that is used to store this oil.

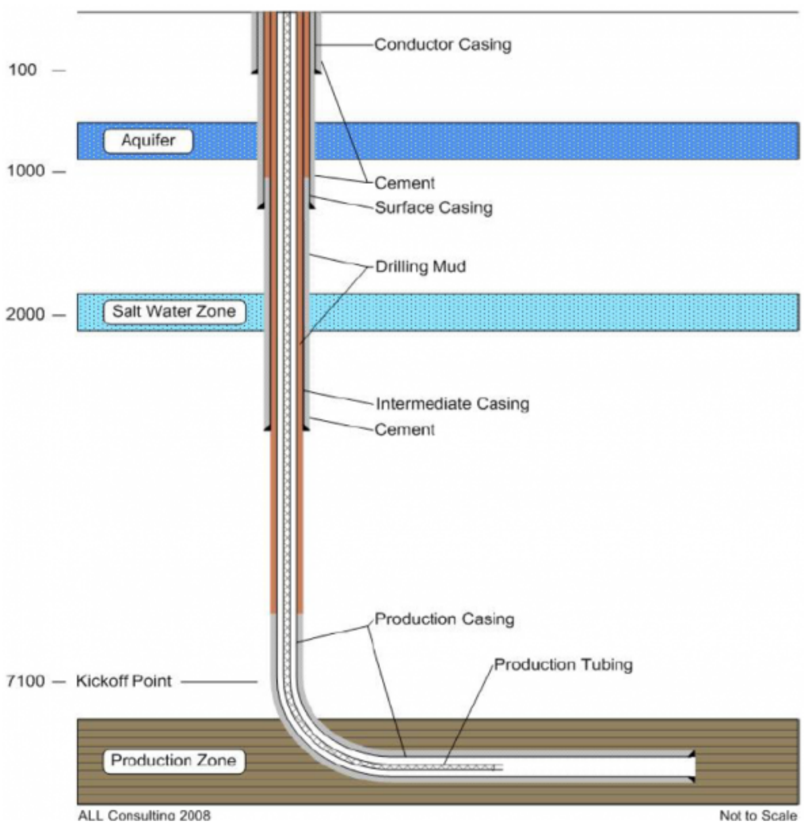
Failure Modes

There are many risks and failure modes associated with the various types of underground hydrocarbon storage. The types of possible negative outcomes depend on the nature of the geology and the location in which the storage reservoir is developed. There are factors that are unique to each well, including fault lines and distance to freshwater, and for that reason, risk analysis studies must be conducted on each well in order to minimize the possible negative outcomes. These will be further discussed in the next section. First, we will explore possible common risks associated with storing oil in depleted hydrocarbon wells that would result in leakage and contamination of nearby environments.

Unsealed Casing

Faulty casings are frequently the culprit for well leakage, with well integrity playing a key role higher in wells.

The casing* is the portion of the well that is set inside the drilled portion as tubing to protect the sides of the well and ensure that there will be no leakage of oil into the upper rock layers.[24] Most oil pockets are far below the surface -- the average depth of crude oil wells is between 5,000 and 7,000 feet.[25] This means that in order to access this oil, developers must drill through other rock layers, including aquifers, which are generally shallower than oil wells. In fact, most oil and gas wells that have been drilled pass through a water table.[26]



Cross section of oil well casing [27]

Frequently, faulty casings are the culprit for well leakage.[28] The problem is not far below the surface in the oil pockets, but rather higher up, with the integrity of the wells. Unsealed cementing and casing cause most of the problems. In addition, cement can deteriorate over time, shrink, develop cracks and channels, or be lost into the surrounding rock. When examining the negative environmental impacts of fracking, one study found that the primary point of leakage was not the fissures created deep below the surface, but rather the casing.[29] By looking at eight different contamination events, only one was caused by underground well failure. The other seven were caused by the cement casing and steel tubing used to line the well. This study estimates that 15% of cement sealings may be imperfect. Applying this estimate to the more than 130,000 inactive wells in Texas shows that close to 19,500 wells may have faulty sealings.[30]

Methane can also leak through well casings. Older wells, wells with greater circumference and therefore larger casings, and wells that deviate from a vertical drill line have shown to be more likely to leak methane into groundwater wells.[31] An analysis of oil and gas wells in Northeastern British Columbia determined that 11% of wells reported methane leaks from wellbores and poorly sealed casings.[32] Wellbores provide a connection of layers that naturally remain geologically isolated, causing contamination of aquifers and surface waters from gases, brines, liquid hydrocarbons, and hydraulic fracturing fluids.

Faulting

Faults in oil and gas wells are a potential source for leakage into nearby aquifers. When faults are reactivated due to the stresses placed on them, they tend to leak. One study that evaluated fault reactivation in the northern North sea determined that fault reactivation and therefore hydrocarbon leakage was caused by three factors:[33]

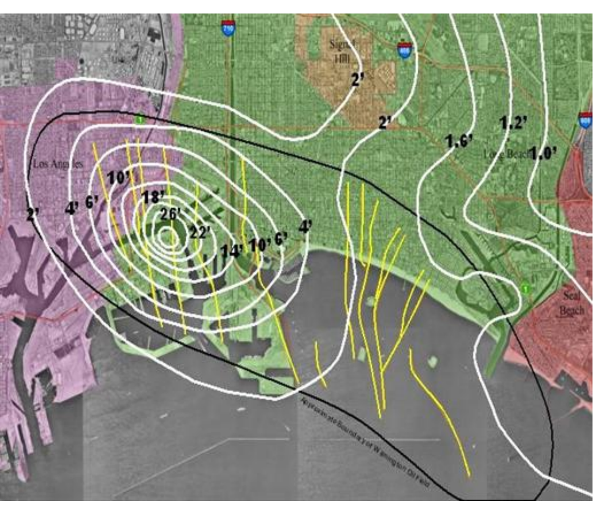
- hydrocarbons in reservoirs abutting the faults, causing locally elevated pore pressure,
- frictional slip* in faults that are aligned in relation to the existing stress field, and
- a recent perturbation of the compressional stress in the fault.

According to the study, a combination of these factors can induce fault slippage and therefore gas leakage. It is important to realize that natural faults and fractures are more common than generally expected, so it is not unlikely that a well will be near a fault or fracture that could slip when the pressure changes due to newly injected oil.[34]

Surface subsidence at Wilmington Oil Field

Subsidence in Wilmington Oil Field began in the 1940s, and reached 29 feet near the center by 1958.

Map of subsidence at Wilmington Oil Field



Surface Subsidence and Uplift

Another possible failure mode that exists when injecting and extracting oil from depleted wells is surface subsidence and uplift.

Surface subsidence* occurs when the ground sinks because of underground material movement.[35] The cause of this is most often the removal of water, oil, natural gas, or mineral resources from the ground, although it can also be caused by various natural events. These changes can happen over areas as small as a few square feet or as large as a state. Subsidence can cause damage to structures at the ground level as the surface caves in and sinks from the original ground level.[36] One notable case of surface subsidence is in the Wilmington Oil field in Southern California. Because of extensive oil recovery in the field, significant surface subsidence occurred, with the ground dropping up to 29 ft in some areas.[37] In order to mitigate the subsidence, sea water was injected into the field to maintain reservoir pressure, which had dropped when oil was removed. Subsidence poses a risk when initially extracting oil from wells and when re-extracting oil that has been stored in a depleted reservoir.

Surface uplift* is caused by the subsurface injection of fluids, including water, gas, and vapour. Different areas experience different quantities of uplift, ranging from a few millimeters to tens of centimeters.[38] Presently, there are no cases in which oil injection caused surface uplift, but this may be the case because oil has never, or very rarely, been injected into depleted wells as a storage solution. One notable case of surface uplift occurred near a wastewater disposal well in Ken Regan field, West Texas. Analysis revealed that casing failure or sealing problems with the well caused wastewater to leak into a nearby aquifer and the ground surface to rise.[39] Although cases of surface uplift have been less drastic than those of subsidence, there is still a risk posed to surrounding infrastructure.

Overpressuring Formations

Depleted oil wells have not been used as an oil storage mechanism in the past. However, these wells have been used to store other contaminants and wastewater in order to keep them isolated from our water sources and away from people. Wastewater injection wells* are used to store contaminated water from fracking. These wells have the same structure as those that are used for oil and gas drilling. Under EPA guidelines, there are six classes of disposal wells, with classes 1 and 2 containing industrial and municipal waste, and oil and gas related waste, respectively.[40] These are the deepest wells of all the classes.

There are a multitude of well failures and leaks associated with these types of disposal wells, and several cases, including one in which brine that was injected into one well came through the surface of other well holes in Chico, Texas in 2003, have demonstrated the high capacity for failure.[41] Several common sources of injection well failure include:

- holes and cracks in the well structure, causing leakage,
- breakdown of cement casings or plugs over time, causing leakage,
- injection of waste at too high of a pressure, causing shattering of containing rock, and
- the presence of injection wells, fracked wells, and abandoned wells in close proximity, reducing the deep underground geology protections.

The last two instances result from over-pressuring the formation, which can cause leakage within the well or trigger fluids to rise up to the surface through other bore holes. When using a depleted oil well for oil storage, knowledge of these issues must be taken into account –oil must not be injected at too high of a pressure, and the surrounding area must be checked to ensure that there are no other wells within a close radius.

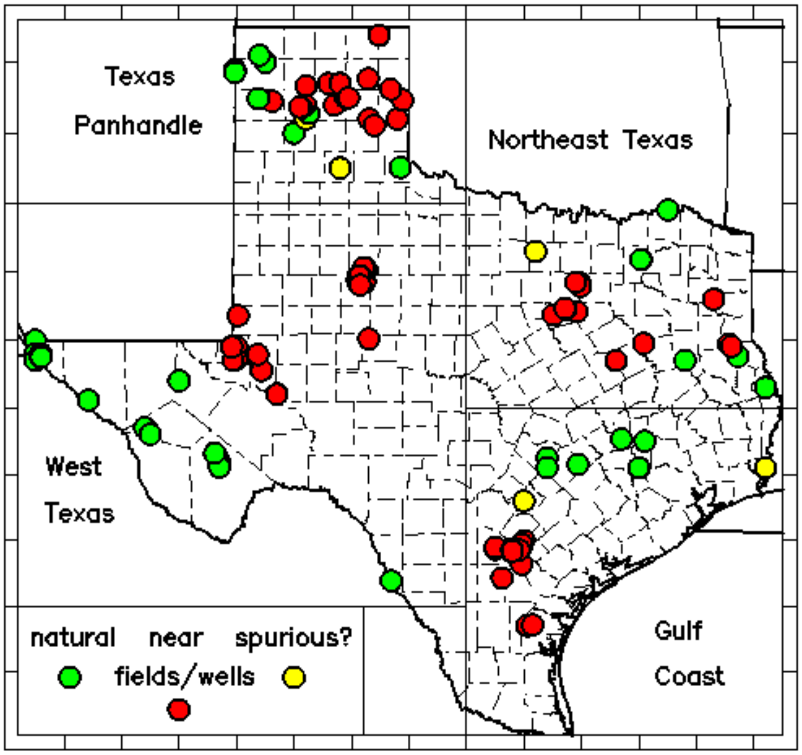
Texas has more hazardous industrial waste wells for oil and gas byproducts than any other state. One-third of class 2 wells in Texas in 2010 had testing violations, with operators not performing the required mechanical integrity tests every 5 years.[42] These wells had high failure rates, so the Texas legislature took action. This was done through doubling the radius that must be checked around an injection well to minimize leakage into other wells. In addition, new regulations on the speed at which waste could be injected into wells were established. However, there continued to be no monitoring on the quantity of waste injected. State oil and gas regulators pushed back on the federal tightening of regulations, changing the definition of waste so that oil and gas drilling byproducts were not included.

Earthquakes

Earthquakes are a potential risk associated with injecting and storing oil into wells in two ways. The first is related to causing earthquakes, while the second pertains to the potential damage that earthquakes can cause to oil and gas wells, causing leakage.

Hydraulic fracturing*, or fracking, began its rapid growth in the US in 2011, and in 2015 it accounted for more than half of oil production in the country.[43] Fracking produces significant amounts of toxic wastewater, which in turn creates demand for storage locations. Injection wells became increasingly common to "safely" dispose of this waste, triggering a surge in earthquakes across the US. For example, Texas experienced a surge in seismicity since 2009, experiencing more than 7,000 small earthquakes.[44]

When fluid is injected at depth, it is sometimes hydraulically connected to faults.[45] As the fluid pressures increase within the faults, this counteracts the present frictional forces, making earthquakes more likely to occur. Researchers at UC Santa Cruz investigated this phenomena, and discovered that "a single injection well can cause earthquakes at distances more than 6 miles from the well." [46] In addition, injecting fluids into sedimentary rocks, which is the preferred practice, can cause larger earthquakes than injecting these fluids into basement rock*. The mechanism behind these distant earthquakes is not the same as that in which fluid pressure rises in faults, which will cause nearby faults to slip. Instead, injecting water into the ground pushes on surrounding rock, creating an elastic stress, which can translate to pressure on faults that are further away without water having been injected into those faults. In some parts of Texas, the majority of earthquake epicenters are near injection wells or active petroleum fields, as shown by the map below.[47]



Map of earthquake epicenters in Texas categorized by proximity to injection wells and active petroleum fields.

According to [this analysis](#) of well integrity during and after earthquakes, there is a possibility of damage to wells during earthquakes.[48] Generally, damage is caused to buildings and other structures during earthquakes because of an inertial response; the ground motion leads to vibration in a building, causing movement of the top relative to the foundation. For wells, since the entire structure is in the ground, this does not present itself as an issue. Relative displacements along the wells could cause damage, and there are three cases in which this would happen. The first is if the well bore crosses a geological fault that ruptures during an earthquake. The second, liquefaction*, poses a very small hazard. During liquefaction, saturated sandy soils completely lose their shear strength, causing them to behave like a liquid. If liquefaction occurs in a layer through which a well is drilled but not in others, this may lead to lateral spreading*, causing a potential loss in well integrity. However, liquefaction mostly occurs at shallow depths of 15 meters or less, and there are few, if any, observed cases in earthquakes with magnitudes smaller than 4.5. Finally, the passage of seismic waves through the area in which the well is drilled can cause deformation of the well casing, but only earthquakes of large magnitudes would exceed the strain limits for the wells, and the likelihood of this happening in Texas is very low. Within the last century, Texas has only experienced five earthquakes with magnitudes between 5 and 6, and none with magnitudes higher than 6.[49]

Analysis of Potential Sites

Well Feature Studies

For any well that is being considered for storage, there is no alternative to a detailed case study in order to drastically reduce the risk of oil leakage. These studies need to involve several components in order to properly analyze all of the features of the chosen well and address any issues that are discovered during this process before any damage is done.

A host of evaluations must be completed, and the time it takes to comprehensively test and analyze the sites will be on the order of a year. Oil and gas companies may use previous data collected on existing and potential drilling areas to hasten the process. It is important to remember, however, that our earth is dynamic, and that information determined in analyses several years ago does not necessarily translate to the current reality. Studies need to include monitoring surrounding geologic formations, using cores to analyze rock layers, using remote sensing such as seismic and sound to gather information on the area, establishing models of the wells, and modeling processes of fluid flow in these formations. In addition to all of this, analyses and precautions that are usually taken with injection wells regarding federal and state regulations, particularly class two wells, should also be taken in these situations.

Essential Considerations

In addition to current processes involved in the analysis of potential storage sites, there are several considerations that must be taken into account when choosing and analyzing a well in which to store oil.

The first of these is the integrity of the casing–a location in the well where there is high risk of leakage. In January 2014, the RRC adopted a rule change to statewide rule 13, and all wells drilled on or after that date must adhere to these changes.[50] These include a requirement for operators to isolate all formations that have a permit for an injection or disposal well within one-quarter mile of the proposed location. In addition, RRC approval must be obtained before setting a casing at a depth exceeding 3,500 feet. Casing and cement quality requirements were also updated: there is a minimum cement sheath thickness of 0.75 inches around the surface casing, and a minimum of 0.5 inches around the other casing strings. Due to this rule change to increase the integrity of the well, it is essential that all wells that are used to store oil be ones created after 2014 to ensure that they adhere to the new requirements and prevent well leakage.

Another consideration is that proper scientific analysis does not always correlate to proper operation of wells. Before the process of injection of wastewater under the ground began, rigorous scientific analysis was performed to make sure that it would be safe and not pose any risk to human health or the environment. However, mechanical integrity violations are very prevalent in injection wells and one-third of class 2 wells in Texas violated testing requirements and standards between 2007 and 2010.[51] The reality is that not only is geology unpredictable, practices by oil and gas companies do not adhere to all the precautions and regulations put in place to minimize risks. Although it is hoped that with rigorous scientific analysis of all potential areas storing oil in depleted wells or other formations would be safe, there will always be risks tied to the process, some of which are virtually unavoidable.

Finally, a reform to the current oil and gas drilling process should be considered. Producers should be incentivized to slow down or stop drilling in times of surplus rather than being deterred from doing so because of additional future costs and leasing risks. This would help to alleviate surplus production and avoid the need for new and potentially risky storage locations.

Recommendations for Additional Research

Ancient Reef Complexes

A series of natural caves are spread throughout the ancient reef complex in the Guadalupe Mountains National Park, located in west Texas. Although the land within the park is protected from oil and gas drilling, this 2008 geologic resource evaluation report raises concerns that "pollutants introduced into the cave complex outside the park have the potential to contaminate caves within the park." [52] Since caverns tend to be attractive sites for underground oil storage, it might be worthwhile to contact the National Park Service and figure out how they are working with energy companies to address these concerns.

Oil and Gas Map Resources

One can get a general idea of where oil fields are in the state from this 2013 production map.[53] Major formations are also mapped on the Texas RRC and US Energy Information Administration (EIA) websites.[54, 55]

Further Concerns for Oil

Besides underground geological formations, underground and above ground tanks for oil storage each pose their own risks for releasing pollutants.

Due to economic pressures from COVID-19, the oil and gas industry will likely see an increase in orphan wells which need to be plugged.[56] These can be identified in the RRC's interactive public GIS viewer for all well records since 1964.[57]

Natural Gas Storage

A report could be done on similarities and differences between oil and natural gas storage.

Permitting Process

Statewide Rule 95

Rule §3.95: Underground Storage of Liquid or Liquefied Hydrocarbons in Salt Formations [58]
Note: major changes under temporary exemption:

- Storage options extended to depleted reservoirs
- Public hearing requirement waived

In order to go through with a project, companies must obtain the necessary permits from the government. They must fill out an H-4 application to obtain a permit from the RRC, and in that application have a letter from the Groundwater Advisory Unit stating the depth of freshwater and relevant groundwater information.

The applicant must also place a public notice of their application for at least once a week for three consecutive weeks in a relevant newspaper. However, these notices are often small and difficult to find. According to Rule 95, the RRC is also required to hold a public hearing for impacted stakeholders and members of the public on all projects, **although the public hearing requirement has been waived under the current exemption.** A public hearing however, is still required if the project is protested. A P-4 form must be filled out in order to transfer a permit.

An emergency response plan is also required, including annual emergency drills that provide a written notice to local officials 7 days prior and submission of an evaluation report 30 days after the drill. If there is an emergency or uncontrolled release, the company must notify local officials and the RRC as soon as possible and report on the root cause of the issue within 30 days as well as issue a report of operational changes within 90 days.

30 days after constructing the well and before solution mining begins, a well completion report is required. After construction, to ensure the underground storage is still safe, companies are required to survey the sites. A sonar survey must happen at least once every 10 years, with the company sending a report on the survey to the RRC within 30 days. Companies must also provide an annual report (H-10H form) on maximum pressures and net volume changes. Additionally, the accuracy of measuring devices must be verified at least once a year by an independent contractor.

When finished with a site, companies are supposed to clean up after themselves by plugging any remaining wells. They must provide notification of intent to plug 5 days prior to doing it and send a report in within 30 days after plugging.

Useful RRC Links Related to Underground Oil Storage

General Hydrocarbon Storage [59]
Details of Exemption [60]
Table of Forms [61]

Definitions

anticline - an arch of stratified rock in which the layers bend downward in opposite directions from the crest.
aquifer - any geological formation containing or conducting ground water, especially one that supplies the water for wells, springs, etc.
basement rock - the oldest rocks in a given area; a complex of metamorphic and igneous rocks that underlies the sedimentary deposits.
casing - the tubular lining of a bored or drilled well.
core - (in mining, geology, etc.) a cylindrical sample of earth, mineral, or rock extracted from the ground by means of a corer so that the strata are undisturbed in the sample.
crude oil - petroleum as it comes from the ground, before refining.
diapir - a dome, or anticline, the upper regions of which have been ruptured and penetrated by material squeezed up from below.
frictional slip - when fault movement occurs due to low coefficient of sliding friction between rocks along faults and other geological processes.
hydraulic fracturing - a process in which fractures in rocks below the earth's surface are opened and widened by injecting chemicals and liquids at high pressure: used especially to extract natural gas or oil. Commonly called fracking.
hydrocarbon - any of a class of compounds containing only hydrogen and carbon, as an alkane, methane, CH4, an alkene, ethylene, C2H4, an alkyne, acetylene, C2H2, or an aromatic compound, benzene, C6H6.
injection well - used to place fluid underground into porous geologic formations. These underground formations may range from deep sandstone or limestone, to a shallow soil layer. Injected fluids may include water, wastewater, brine (salt water), or water mixed with chemicals.
lateral spreading - the finite, lateral movement of gently to steeply sloping, saturated soil deposits caused by earthquake-induced liquefaction.
liquefaction - process by which water-saturated sediment temporarily loses strength and acts as a fluid, like when you wiggle your toes in the wet sand near the water at the beach. This effect can be caused by earthquake shaking.
natural gas - a combustible mixture of gaseous hydrocarbons that accumulates in porous sedimentary rocks, especially those yielding petroleum, consisting usually of over 80 percent methane together with minor amounts of ethane, propane, butane, nitrogen, and, sometimes, helium: used as a fuel and to make carbon black, acetylene, and synthesis gas.
permeability - the capability of a porous rock or sediment to permit the flow of fluids through its pore spaces.
porosity - the ratio, expressed as a percentage, of the volume of the pores or interstices of a substance, as a rock or rock stratum, to the total volume of the mass.
salt domes - a domelike rock structure that is formed beneath the earth's surface by the upward movement of a mass of salt, may reach thousands of feet in vertical extent, and is more or less circular in plan: often associated with oil and gas pools.
shutting-in - to close off a well so that it stops producing.
stratigraphic traps - a natural reservoir in which oil or gas may be confined because of changes in porosity and permeability of the strata rather than as a result of their structural attitudes.
structural traps - a type of geological trap that forms as a result of changes in the structure of the subsurface, due to tectonic, diapiric, gravitational and compactional processes. These changes block the upward migration of hydrocarbons and can lead to the formation of a petroleum reservoir.
surface subsidence - sinking of the Earth’s surface in response to geologic or man-induced causes.
surface uplift - vertical elevation of the Earth’s surface in response to natural or man-induced causes.

Notes

Cover page image: https://en.wikipedia.org/wiki/Oil_well

1. Meredith, S. (2020, April 22). *The hunt for oil storage space is on — here's how it works and why it matters.* CNBC. https://www.cnbc.com/2020/04/22/oil-prices-heres-how-oil-storage-works-and-why-capacity-matters.html
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