Decommissioning orphaned and abandoned oil and gas wells: New estimates and cost drivers

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Abstract

Millions of abandoned wells are scattered across the United States, causing significant methane emissions and creating a variety of health and environmental hazards. Governments are increasingly interested in decommissioning such wells via tougher regulations or direct spending, but want to do so efficiently. However, information on the costs of decommissioning wells is very limited. In this analysis, we provide new estimates of the costs of decommissioning oil and gas wells and the key drivers of those costs. We analyze data from up to 19,500 wells and find that median decommissioning costs are roughly $20,000 for plugging only, and $76,000 for plugging and surface reclamation. In rare cases, costs exceed $1 million per well. Each additional 1,000 feet of well depth increases costs by 20 percent, older wells are considerably more costly than newer ones, natural gas wells are nine percent more expensive than wells that produce oil, and costs vary widely by state. Surface characteristics also matter: each additional 10 feet of elevation change in the 5-acre area surrounding the well raises costs by three percent. Finally, we find that contracting in bulk pays off: each additional well per contract reduces decommissioning costs by three percent. These findings suggest that regulators can adjust bonding requirements to better match the characteristics of each well.

1. Introduction

Millions of oil and natural gas wells have been drilled in the United States since the mid-1800s. While at any given time, some of these wells may be idled for economic purposes and then later brought back into production, a much larger number are permanently idled and not properly decommissioned. The US EPA estimates that as of 2018, roughly 2.1 million wells were not being used for production, injection, or other purposes, but had not been plugged.[1]

This estimate may significantly undercount the true number of such wells in the United States. In the industry's early years, most regulatory programs neither mapped the location of drilled wells nor incentivized operators to decommission sites at the end of their useful lives. As a result, hundreds of thousands—perhaps millions—of additional unplugged wells exist, but are neither mapped nor accounted for in state and federal inventories.[2,3] In the 20th Century, modern regulatory frameworks have emerged and evolved, requiring operators to decommission well sites at the end of their useful lives. Because insolvent operators may be unable to pay for these decommissioning costs, regulators have adopted financial assurance requirements to cover these costs if companies go bankrupt. However, as previous work has demonstrated.[e.g., 4] these requirements are often insufficient to cover the full costs of decommissioning. This problem is particularly germane for the issue of "blanket" bonds, which allow operators to cover all their wells within a state or territory with a single (often low) bond. In addition, operators may idle wells with little intention to reactivate them, but report those wells to regulators as "temporarily" idled to avoid decommissioning obligations.[5]

In the 21st Century, the proliferation of shale gas and tight oil development, which typically involves deep, horizontally-drilled wells, has raised concerns that decommissioning costs for these wells may exceed those of conventional wells because of the former's greater depths and associated pressure.[e.g., 6] In 2020, as oil prices crashed due to a global oversupply initiated by the effects of the Covid-19 pandemic, considerable interest emerged among state and federal policymakers to decommission wells as a way to support unemployed oil and gas workers and to reduce the environmental and climate risks of unplugged abandoned wells.[e.g., 7–9]

Because definitions for what constitutes an "abandoned" well can vary across jurisdictions, it is helpful here to define several key terms as they are used in this paper. We follow the U.S. EPA[1] and define abandoned wells as those with no recent production, injection, or other uses (estimated at 3.2 million). Our focus in this paper is on the subset of unplugged abandoned wells (estimated to account for 2.1 of the 3.2 million total abandoned wells), which are typically the largest emitters of methane.[2] In addition, there is a subset of unplugged abandoned wells known as "orphans," which have no solvent owner and are effectively wards of the state. As noted above, there is large uncertainty over the true number of orphaned wells in the United States.

Looking forward, the number of orphaned wells has the potential to grow considerably if policies to reduce greenhouse gas emissions lead to substantial reductions in oil and natural gas demand. Unlike previous cyclical downturns when struggling companies could sell their less profitable wells to other operators, a structural decline in oil and natural gas demand due to climate policy (or other factors) would make these investments less attractive, leaving few buyers for marginal wells, and ultimately a large increase in the number of orphaned wells that pose risks to the environment and human health.

1.1. Risks of unplugged abandoned wells

Unplugged or improperly plugged oil and gas wells can pose a variety of environmental and health hazards. At the local level, degradation of the cement and steel that make up a wellbore can lead to migration of gases or fluids that may contaminate surface water or groundwater,[10,11] and in some cases accumulations of gases can lead to explosion risks.[12] These hazards can be exacerbated if unplugged wells are proximate to new oil and gas development utilizing hydraulic fracturing.[e.g., 13] Unplugged wells may also endanger human health through emissions of air pollutants such as benzene, hydrogen sulfide, or volatile organic compounds (VOCs), though this exposure pathway has not been studied in the literature to date.[14] In addition, unplugged wells pose a hazard if individuals trip over or step into an unmarked well.

The most closely examined impact of unplugged abandoned wells is emissions of methane, a powerful greenhouse gas and an ozone precursor. The U.S. EPA estimates that, on average, each unplugged abandoned oil and gas well emits 0.13 metric tons of methane per year.[1] Multiplied by an estimated 2.1 million such wells, the EPA estimates methane emissions of 276,472 metric tons annually, equivalent to roughly 9.5 million metric tons (MMT) of carbon dioxide (CO_2) per year assuming a 100-year global warming potential (GWP) of 34; or 24 MMT of CO_2 per year assuming a 20-year GWP of 86.[15] For reference, 2019 CO_2 emissions from all energy use in the nation of Croatia (population ~4 million) was roughly 15 MMT.[16]

As with other aspects of methane emissions across the oil and gas supply chain,[e.g., 17,18] recent studies have found that a small number of wells may contribute a large share of the total, with the highest emitters wells contributing as much as 0.66 metric tons per year for one unplugged abandoned gas well[19] and 1.16 metric tons per year for one "shut-in" oil well.[11] Although data remain quite limited, emissions rates appear to vary across well types (i.e., oil or gas wells), geology, and—most importantly—plugging status, with unplugged wells typically emitting more methane than plugged wells.[e.g., 2,20,21,19,22–24]

Although there are considerable uncertainties surrounding the magnitude of environmental risks, some recent evidence has suggested that proximity to unplugged oil and gas wells reduces property values considerably. In a working paper, Shappo[25] estimates that property values are roughly $15,000 (11%) lower for Pennsylvania homes within two kilometers of unplugged wells compared with similar homes that are not close to unplugged wells. Importantly, the analysis finds that home values fully recover if the well is properly decommissioned, suggesting that the benefits of decommissioning may outweigh their costs, even without accounting for the climate damages associated with methane emissions.

Another recent analysis[26] estimates substantial ecosystem service benefits from decommissioning wells, including agricultural use, CO_2 sequestration, and other services. The authors estimate that the present value of ecosystem service benefits from restoring the surface at 430,000 well sites would be $21 billion, or $49,000 per well.

1.2. Existing decommissioning cost estimates

Policymakers in recent months have proposed spending billions of dollars to decommission unplugged abandoned wells, often focusing on the subset of orphaned wells.[e.g., 7,27,28] However, limited information on the location, environmental damages, and decommissioning costs for these wells make it difficult for state and federal policymakers to identify how to prioritize among the millions of wells that could plausibly be targeted for decommissioning.

Along with uncertainty over the benefits of decommissioning (e.g., reducing methane emissions), there is considerable cost variation, making planning difficult for policymakers. Mitchell and Casman[29] make a rough estimate that decommissioning shale gas wells in Pennsylvania would cost between $100,000 and $700,000 per well. Ho et al.[4] use cost data from plugging conventional wells in 11 states (excluding reclamation costs) and find that average costs range from less than $5,000 per well to roughly $50,000 per well at the high end. A 2020 report from the Interstate Oil and Gas Compact Commission[3] aggregates data from over a dozen US states, estimating that decommissioning costs have averaged roughly $24,000 per well, with wide variation.

Recent policy reports have estimated costs ranging from roughly $27,000 to hundreds of thousands of dollars per well for certain well types.[6, 9] There are many factors affect plugging and decommissioning costs. To develop better cost estimates, this paper substantially expands the dataset analyzed by Ho et al.[4] and examines how different well characteristics, such as depth, age, and other factors, may affect decommissioning costs. By developing detailed measures of decommissioning costs, this paper will help inform decisions about which wells to plug to cost-effectively address environmental hazards.

2. Data and methods

Our initial dataset includes decommissioning costs for more than 19,500 oil and gas wells, the largest dataset that has been assembled to our knowledge. Data were gathered via email from state regulators in Kansas, Montana, Pennsylvania, and Texas. Costs were provided at the contract level, where state regulators contract with oilfield service providers to decommission one or more orphaned wells. For Kansas and Texas regulatory data, these costs only include plugging (i.e., exclude site reclamation). We also gathered proprietary decommissioning costs from New Mexico and Texas from several hundred wells from one large oil and gas operator, which include plugging and restoration costs. Using unique API identification numbers, we matched more than 10,000 wells in these contracts to oilfield data from Enverus (formerly DrillingInfo), allowing us to gather information about well location, depth, age, production type (e.g., oil or gas), drill type (e.g., vertical or horizontal), and more (due to differences in reporting and recordkeeping, complete data were not available for all wells).

Because cost data from states were often provided at the contract level (rather than the well level), our unit of observation is the contract. When contracts include more than one well, we average information across each well of the contract (e.g., plugging cost, well depth, age of well). This process is unlikely to bias the data because when state regulators award contracts for plugging multiple wells, those wells are located close to one another, have similar ages, and share other key characteristics such as depth and production type. Using the contract as our unit of observation also allows us to estimate the extent to which contracting in bulk provides any economies of scale.

More than 7,500 wells across 3,997 contracts included complete, or close to complete data, allowing us to perform statistical analysis on this subset of contracts. Tables 1 and 2 present summary statistics for decommissioning costs and other characteristics for contracts that involved only plugging (Table 1) and plugging and site remediation (Table 2). For plugging only, costs average roughly $20,000, while plugging and remediation costs average $76,000 across states. In rare cases, costs exceed $1 million per well.

Table 1 Decommissioning costs (plugging only)

State	KS	TX	Total
No. of contracts	804	2,280	3,084
No. of wells	≥804	5,413	≥3,888
Avg. wells per contract	Unknown	2.4	Unknown
Mean cost per well ($2019)	$6,568	$25,055	$20,318
Median	$4,627	$18,708	$14,451
Minimum	$1,073	$1,440	$1,073

Maximum	$78,544	$2,205,800	$2,205,800
P.10	$2,383	$5,556	$3,422
P.90	$12,305	$40,884	$37,038
Avg. depth	1,295	4,232	3,466
Avg. first year	1969	1984	1982
Avg. plug year	2006	2018	2015
Share vertical or unknown	100%	97%	98%

Table 2 Decommissioning costs (plugging and site remediation)

State	MT	NM	PA	TX	Total
No. of contracts	204	158	103	448	913
No. of wells	≥204	158	717	448	≥1,527
Avg. wells per contract	Unknown	1	7.0	1	Unknown
Mean cost per well ($2019)	$15,335	$171,652	$48,703	$75,307	$75,579
Median	$9,504	$132,319	$24,065	$58,525	$52,629
Minimum	$266	$8,043	$3,832	$1,859	$266
Maximum	$222,275	$1,115,711	$469,274	$1,645,103	$1,645,103
P.10	$2,507	$71,677	$5,730	$22,373	$7,620
P.90	$27,583	$307,178	$124,292	$130,481	$159,764
Avg. depth	2,409	5,987	2,056	4,226	3,880
Avg. first year	1959	1988	1963	1976	1973
Avg. plug year	2007	2016	2002	2016	2013
Share vertical or unknown	100%	93%	99%	100%	99%

In our analysis, we examined dozens of factors that could plausibly affect decommissioning costs. Some of these data can be observed through data on the well itself, while others must be gathered using geospatial software. We use ArcGIS Pro and ArcGIS Online software[30] to gather these geospatial characteristics.

Based on previous research and conversations with experts from industry, the regulatory community, and other researchers, we developed hypotheses about how different factors may affect costs. These are:

(1) Well depth: Deeper wells are more expensive to drill than more shallow wells.[31] We hypothesize that the same relationship would apply to decommissioning wells.

(2) Well age: Because well integrity may degrade over time,[32] we hypothesize that cleanup costs vary linearly with well age.

(3) Site topography: We hypothesize that sites in hilly terrain will be more costly to decommission than those in flat terrain because of erosion concerns, getting materials to the site, and other reasons. Plugging wells may also be more costly if the well itself is on a slope, which would make it more difficult to stabilize equipment, or require additional site preparation (i.e., land grading).

(4) Surface restoration: Other things equal, wells where both the well itself and the surrounding well pad are remediated will be more costly to clean up than sites where the only actions are to plug the well.

(5) Wells per contract: While absolute costs will rise with the number of wells under contract, we hypothesize that there will be economies of scale for larger contracts, resulting in lower per-well costs for contracts with more wells.

(6) Oil vs. gas well: We hypothesize that gas wells are harder, and therefore more costly, to decommission because the gas naturally flows to the surface, while a non-producing oil well has presumably lost most of its natural pressure (although associated gas may still be an issue). However, it is also possible that oil wells will be more costly to decommission because they may be more likely to have surface spills that need to be remediated.

(7) Location: Ho et al (2018) show that state regulations affecting site clean-up and well plugging vary widely. In addition, differences in regional markets for oilfield services may affect labor and equipment costs. Therefore, it would not be surprising to find that costs vary across states.

Table 3 summarizes the variables that we include in the statistical analyses that follow and the sources from which they are gathered, with details provided in the SI. As noted above, complete data for these variables were available for 3,991 out of our total of 3,997 contracts (2,984 contracts included details on the number of wells per contract, which were not available for Kansas and Montana).

Table 3 Variables that affect decommissioning costs

Variable	Hypothesized effect on cost	Data source
Well depth	Deeper wells may require additional labor and materiel	Enverus
Well age	Older wells may be more degraded	Enverus
Topography	Wells in hilly areas may be more costly to plug and restore the surface	ESRI via ArcGIS
Surface restoration	Restoring the surface will add costs above simply plugging the well	Regulators
Wells per contract	Contracts with more wells may offer economies of scale	Regulators
Well type	Gas wells may differ from oil wells or oil & gas wells	Enverus
State	State regulations or other factors may affect plugging costs	Regulators

Notes: ESRI = Environmental Systems Research Institute

We tested a substantial number of additional variables we hypothesized could plausibly affect costs. These variables include proximity to water bodies, depth of water table at the well site, land use type, distance to population centers, distance to roads, oil and natural gas prices, and other factors. However, these factors did not meaningfully improve the predictive value (Adjusted R^2 score) of the model, and because of data limitations, they substantially reduced the statistical power of our analysis. For those reasons, we exclude these variables and results in the following analysis.

Because plugging costs are highly skewed to the right (see SI Figures S1 through S4), we conduct a logarithmic transformation and use the natural log of cost as our dependent variable. We then develop a log-linear regression model in our analysis.[33]

3. Regression results

Our analysis reveals numerous statistically significant and economically meaningful results. Table 4 presents two specifications. The first, our central specification, includes data from 3,991 contracts across five states, while the second, which includes 2,984 contracts, adds the variable for the number of wells per contract, which was not available for Montana or Kansas. All the results shown in the table are statistically significant at the p>0.99 level or above.

Table 4 OLS Regression Results

Dependent variable: Change in natural log of decommissioning cost				
	Specification 1		Specification 2	
Variable	Estimate	Std. error	Estimate	Std. error
Surface reclamation[1]	1.18	0.03	1.14	0.03
TVD (thousand feet)	0.20	0.004	0.18	0.004
Age <20[2]	-0.23	0.04	-0.33	0.04
Age 20-40[2]	-0.17	0.03	-0.27	0.04
Age 40-60[2]	-0.09	0.03	-0.16	0.04
Oil well[3]	-0.09	0.03	-0.12	0.03
Montana[4]	-1.15	0.08	Omitted due to lack of data	
New Mexico[4]	0.94	0.08	0.86	0.08
Kansas[4]	-0.35	0.08	Omitted due to lack of data	
Texas[4]	0.38	0.07	0.26	0.07
Wells per contract	Omitted due to lack of data		-0.03	0.003
Elevation range (hundred feet)	0.26	0.07	0.37	0.08
Constant	8.73	0.07	9.10	0.08
Diagnostics				
R-squared	0.69		0.63	
No. of observations (contracts)	3,991		2,984	

1: Compared with wells that are plugged only. 2: Compared with wells 60 years or older when plugged. 3: Compared with gas only well. 4: Compared with Pennsylvania. Note: Because we do not have data on the number of wells per contract for Montana and Kansas, they are omitted from the regression analysis due to collinearity.

As suggested by the differences between Table 1 and Table 2, site restoration more than doubles the cost of well decommissioning, increasing them on average by 118 percent in our preferred specification when controlling for other variables. As expected, deeper wells are also more costly, with each additional 1,000 feet of total vertical depth increasing costs by 20 percent on average. The age of the well also correlates strongly with costs. Compared with wells that were more than 60 years old when decommissioned, wells aged 40 to 60 years old were nine percent less expensive, and wells aged from zero to 40 were roughly 20 percent less expensive. Higher costs for older wells are likely caused by degradation of steel and cement casing over time, which can create multiple challenges for plugging operations.

We also find that wells producing only natural gas are nine percent more expensive to decommission than wells that produce oil (many of these wells produce both oil and natural gas). Based on discussions with industry experts, the additional time and equipment that is often needed to stop the (often high-pressure) flow of natural gas during well plugging operations, particularly in older wells, explains this difference. For wells producing oil, experts reported that while surface oil spills were costly when occurred at large scale, they were relatively rare.

We found significant variation in costs by state. Compared with decommissioning in Pennsylvania (our reference state), costs in New Mexico and Texas are 94 and 38 percent higher, respectively, while costs in Montana and Kansas are 115 and 35 percent lower, respectively. Three potential explanations may play a role: First, differences in state regulatory requirements may contribute to variation in costs. Second, contractor costs may vary regionally due to variation in local supply and demand. For example, Ho et al.[4] found wide variation in service provider costs between Kansas, Pennsylvania, and Texas, with relatively high costs found in Texas (they did not examine data for New Mexico). Third (applicable only to Texas and New Mexico), as noted in Section 2, most of our data was provided by state regulators, who contract with service providers to decommission orphaned wells. However, all our New Mexico data, and roughly 16 percent of our Texas data, come from a private company decommissioning their own wells at the end of their economic lives. This company reported to us that they go above and beyond regulatory requirements in the states where they operate, which would help explain the higher costs in New Mexico and Texas. However, we have no way to verify this claim.

Topography also appears to affect decommissioning costs. For each additional 10 feet of elevation change in the 5-acre area surrounding each well site, decommissioning costs increased by roughly 3 percent. For reference, a standard professional soccer pitch is typically 1.75 acres, and many modern oil and gas well pads are roughly one acre in size. Substantial changes in elevation could add costs for surface remediation, which typically involves heavy machinery, along with making it more difficult to site and stage a drilling rig or other equipment needed to plug the well.

Finally, our second specification allows us to examine the effects of economies of scale with respect to decommission costs. For each additional well on a given contract, decommissioning costs fall by roughly 3 percent per well, though data are not available for Kansas or Montana. This intuitive result likely reflects the economies of scale that oilfield service firms can achieve through reducing administrative and on-site costs, particularly when multiple wells on the same contract are located close together.

4. Discussion and policy implications

This paper yields a variety of insights that can better inform private and public entities as they consider the future costs of safely decommissioning oil and gas wells.

First, these estimates can inform policy decisions related to financial assurance requirements for oil and gas operators. As noted above, all states and the federal government require companies to provide some type of financial assurance to decommission their wells if they become orphaned due to bankruptcy. However, these requirements are often orders of magnitude below the true decommissioning costs, especially for blanket bonds that can cover hundreds of wells in a given jurisdiction, as discussed in Ho et al.[4] Our results reinforce this finding: although some states set blanket bond levels as low as $15,000 (Ohio) or $25,000 (Pennsylvania) to cover every well in a state,[3] our median decommissioning cost is roughly $75,000 per well.

Our results suggest that, because they significantly affect decommissioning costs, financial assurance requirements should account for key factors including well depth, well age, and well type (oil, gas, or oil & gas). Our results can help regulators quantify the likely relationship between these factors and plugging costs. For example, our model estimates that fully decommissioning a 30-year-old oil well in Pennsylvania with total vertical depth of 2,000 ft. will cost, on average $23,377, while an 80-year-old gas well in Texas with depth of 6,000 ft. will cost $97,801 (assuming no elevation change and one well per contract). Thus, tying bonding requirements to these factors and ending the discount for blanket bonds (other than that based on observed economies of scale, such as that in this paper) could reduce the proliferation of future orphaned wells, but not necessarily raise bonding requirements for all operators.

Relatedly, these estimates quantify the benefits to state regulators (and, perhaps, oil and gas companies) of contracting in bulk to decommission wells. Although we are not able to observe the mechanism, which could include competitive bidding pressures and legitimate economies of scale, we found that bulk contracting reduces per-well costs by more than 3% per well. These results suggest that policymakers can get more “bang for the buck” by seeking to contract in bulk.

Third, our estimates quantify the intuitive but important finding that reclaiming the site surface adds considerable costs to decommissioning operations. This implies that if policymakers care most about reducing methane emissions and risks to groundwater, it may be wise to focus only on plugging wells without remediating the surface. If, on the other hand, surface reclamation is a priority for environmental, aesthetic, job creation, or other reasons, our results will help policymakers quantify the costs associated with achieving those additional benefits (and perhaps adjust bonding requirements accordingly). One recent analyses suggests that restoring the surface can have large ecosystem service benefits,[26] though these benefits will vary considerably by region and land use type.

5.Conclusion

Millions of oil and gas wells will need to be decommissioned in the United States over the coming decades. Many of these wells leak methane, a potent greenhouse gas, and many pose additional environmental and health hazards. However, limited data means that it is difficult to know which wells are most likely to pose the greatest hazards, and in many cases, orphaned wells are undocumented and unmapped. At the same time, reliable information on the costs of decommissioning wells, and how those costs vary across key characteristics, has not been available. Although some of these costs will be borne by companies and their investors, other costs will fall upon taxpayers through spending by federal, tribal, and state governments.

Policymakers need better information on both sides of the ledger to develop policies that incentivize or require companies to bond and decommission their wells, and to make decisions about the appropriate scale of public dollars to devote to this environmental and health issue.

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Supplementary Information

SI 1. Variables

Table S1 provides additional information on the variables we analyzed. As noted in the paper, not all variables improved the explanatory power of the model, and as such were excluded from our final regression specification. The variables that were included in the final regression are bolded in the table below.

Table S1. Factors that could plausibly affect decommissioning costs

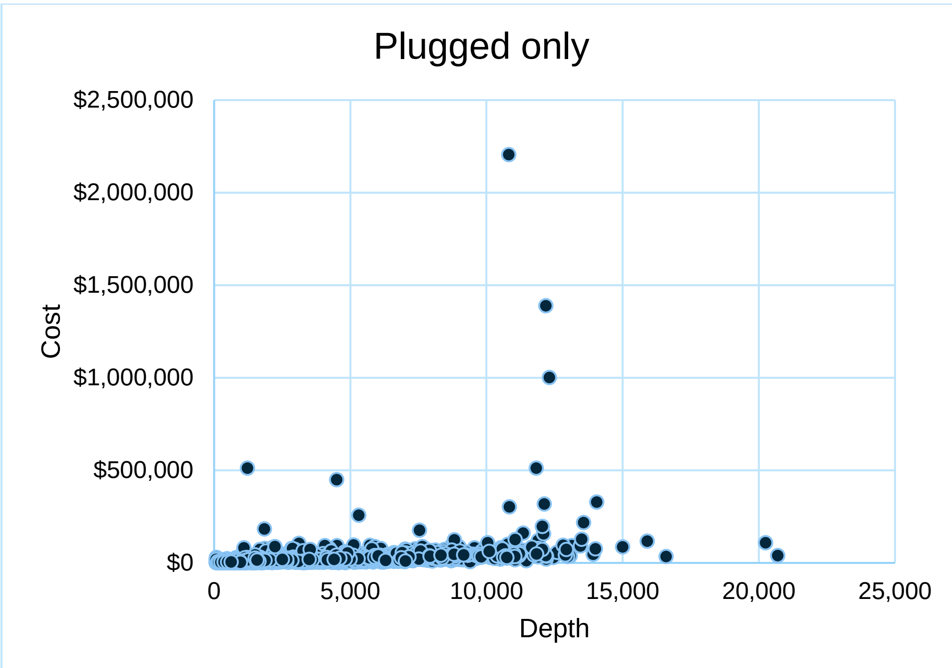
Variable	Variable Type	Description
Well depth	Continuous	Total vertical depth (TVD) is used, which includes only the vertically-drilled portion of the well. Horizontal lengths are typically not plugged during decommissioning activities.
Wells per contract	Continuous	This information was provided by state regulators and one private company.
Well type	Binary	This information was gathered through Enverus' DrillingInfo online application using API numbers provided by regulators and one private company. Wells were classified as either oil, natural gas, or oil and gas.
State	Binary	This information was provided by state regulators and one private company. Location information gathered through Enverus' DrillingInfo online application using API numbers confirmed the location of the wells.
Drill type	Binary	This information was gathered through Enverus' DrillingInfo online application using API numbers provided by regulators and one private company. Wells were classified as either vertical, directional, or horizontal.
Well age	Binned	This information was gathered through Enverus' DrillingInfo online application using API numbers provided by regulators and one private company. We take well age as the number of years between when the well was plugged and when it was either spud, completed, or first produced. We bin wells into 20-year groups, including wells 20 years or younger, 20 to 40, 40 to 60, and over 60.
Land use	Binary	This information was gathered from the 2016 National Land Cover Database (NLCD) , which includes 20 land use types. Wells in our database were found to be in 15 land use types. We consolidate these 15 types into 5 groups: agricultural, developed, forest, grassland/scrub, and other. Data are gridded in cells of 30 by 30 meters. Because well pads are not a single point, and decommissioning activities occur around the site, we classify sites based on the modal land use in the five acres surrounding the well.

Coal overlay	Binary	We gathered the location of coalfields in the United States from the ESRI database "USA Coal Fields," which includes the location of mineable deposits of coal, including both surface and underground deposits.
Elevation change	Continuous	This information was collected from ESRI's "Terrain" imagery service, which aggregates the best available elevation data. Because well pads are not a single point, and decommissioning activities occur around the site, we use the range of elevation in the five acres surrounding the well. To calculate the range, we subtract the lowest point of elevation from the highest point in the five-acre area.
Distance to water	Continuous	Vector stream data were collected from ESRI's "USA Detailed Streams" feature service. Water body polygons for data were gathered from the National Hydrography Dataset Plus Version 2.1. We calculated distance to water using the well location and the nearest location of a stream, reservoir, lake, or pond.
Energy prices	Continuous	This information was gathered from the US Energy Information Administration, using average annual values for oil prices (West Texas Intermediate spot price) and natural gas prices (Henry Hub spot price).
Distance to population center	Continuous	This information was gathered from the ESRI feature service "USA Census Populated Places." We calculated distance to population centers using the well location and nearest location of any population center. We also tested this variable using only larger population centers (e.g, population of more than 100,000).

SI 2. Visualizing depth and cost data

The figures below illustrate the logged and unlogged price vs. depth data.

Figure S1. Cost and well depth



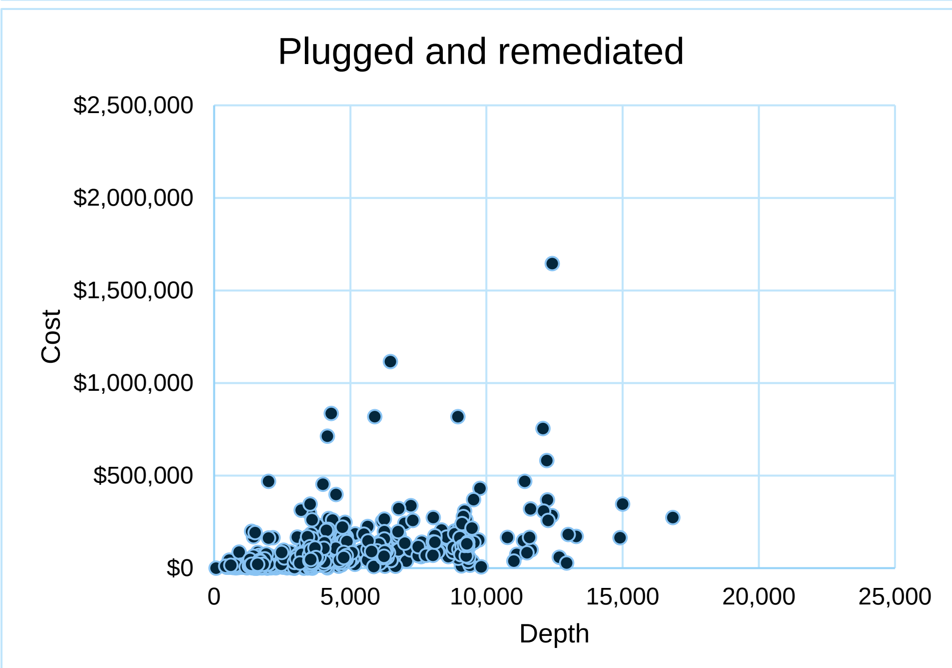
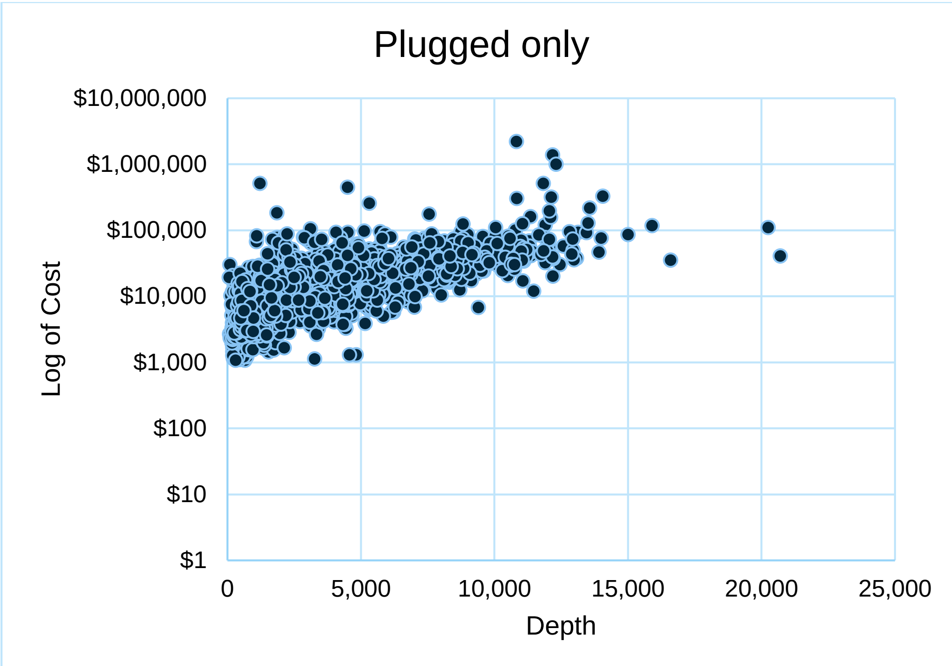


Figure S2. Log of cost and well depth



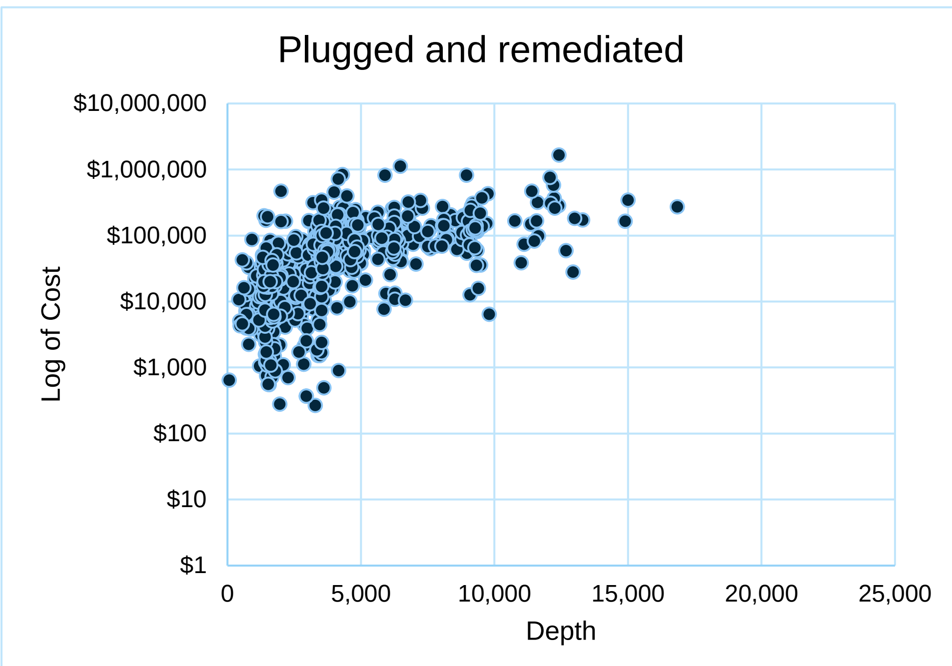
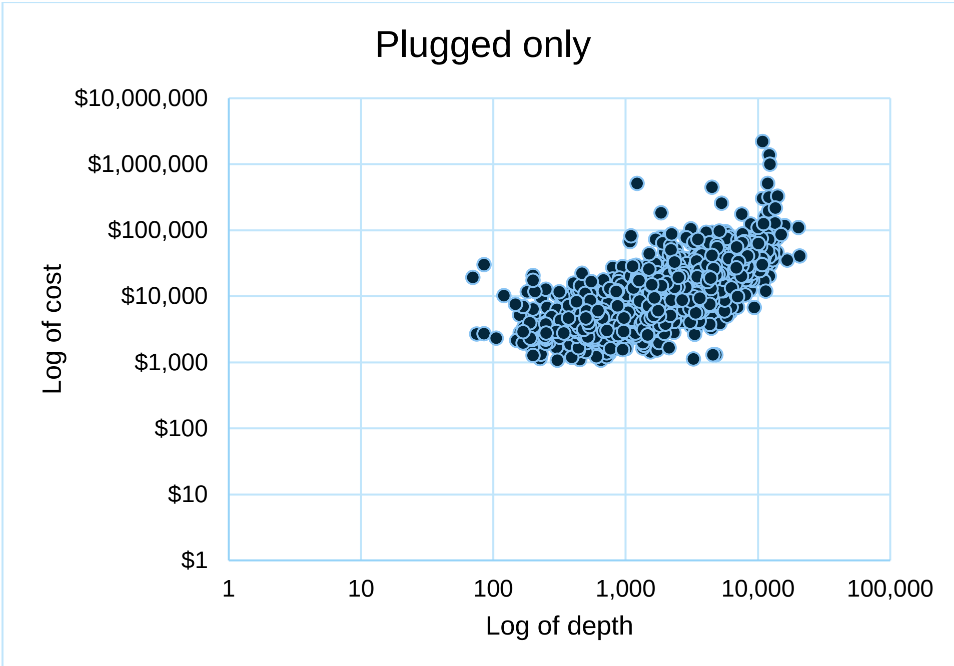


Figure S3. Log of cost and log of well depth



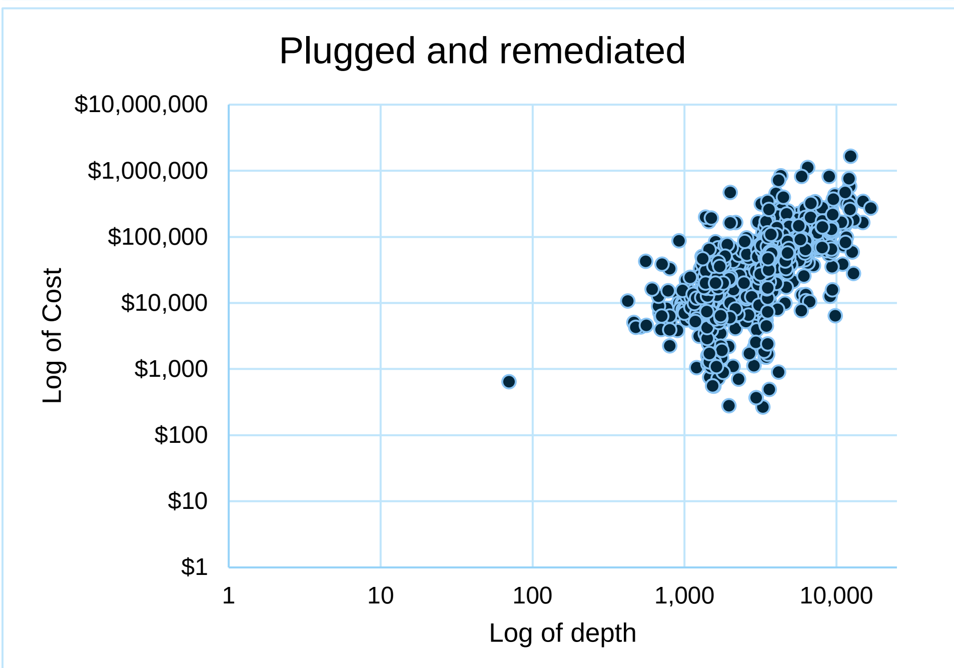


Figure S4. Distribution of plugging costs (real $2018)