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Methodology for Defining and Compiling Abandoned and Active Hydrocarbon Well Inventories

Scientific Investigations Report 2025–5030

U.S. Department of the Interior
U.S. Geological Survey

Cover. Abandoned gas well on refuge lands. Photograph by Steve Hillebrand, U.S. Fish and Wildlife Service, 2015.

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Abbreviations

PIDM	Petroleum Information Data Model
USGS	U.S. Geological Survey
UWI	unique well identifier

Methodology for Defining and Compiling Abandoned and Active Hydrocarbon Well Inventories

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Abstract

Hydrocarbon wells are not active forever; when they become permanently disused (abandoned), well infrastructure must be remediated or repurposed. Knowing which wells are abandoned is the initial and often complicated step in taking responsibility for well infrastructure. Each State creates laws and regulates hydrocarbon operations, which includes well abandonment. The existence of multiple regulating authorities means definitions of abandonment are mostly found in legal documents are broadly defined or other terms are used. This report presents a technical approach to defining hydrocarbon well abandonment using well production data and identifies abandoned hydrocarbon wells using the new definition.

Introduction

Commercial hydrocarbon (oil, natural gas, gas condensate, and casinghead gas) production in the United States has been occurring since 1859 (Wells and Wells, 2016). The commercial hydrocarbon production lifecycle typically consists of exploring for commercially significant hydrocarbon accumulations, developing and producing the resource by drilling wells, and then abandoning hydrocarbon production once the economically recoverable resource has been produced. There have been numerous reports and publications identifying commercially significant hydrocarbon accumulations (for example, refer to Nehring and Van Driest, 1981, and Finn and others, 2024). Indeed, there are journals devoted to describing these accumulations and the geologic processes that produce them (for example, the American Association of Petroleum Geologists journal). Additionally, there are many summary publications on the development and production of hydrocarbon accumulations (for example, Jahn and others, 2008, and Hyne, 2019). Although a less voluminous area of research, end-of-production publications focus on specific aspects of abandonment like policy or emissions (for example, Chukwuemeka and others, 2023; Brandt and others, 2014; and Townsend-Small and others, 2016). These publications either don't define hydrocarbon well abandonment or use attributes like status when defining abandonment.

When hydrocarbon well abandonment is specifically defined, it is usually in the context of a larger legal document (for example, U.S. Department of the Interior, 2023) or a section of a larger report (for example, Townsend-Small and others, 2016). Another complication is that there are multiple terms that represent the same or a similar idea. Terms such as "orphan," "plugged and abandoned," "temporarily abandoned," and "non-producing" all indicate that a well is inactive; their meanings only vary in the status of inactivity. For example, an "orphan" well is an inactive well with no information on whether the well has been shut-in or properly abandoned "Shut-in" is a term used for a well that is inactive, usually temporarily (International Standards Organization, 2017). These terms, definitions, and prior research, although useful, are not ideal for defining well abandonment because the definition is either overly specific or tangential. Legal definitions of well abandonment are precise but can rely on other factors, like economics. Economic factors do not take into account technical considerations of well operations and focus on monetary changes. Additionally, publications on hydrocarbon well abandonment tend to focus on specific aspects of well abandonment (for example, greenhouse emissions from abandoned hydrocarbon wells, such as U.S. Environmental Protection Agency, 2022). In comparison, defining abandonment using hydrocarbon production and well data based on analysis of those data is unique. Using hydrocarbon well and production data presents a challenge because there are a range of sources and differing regulatory frameworks.

The methodology in this report relies on U.S. hydrocarbon data. Before hydrocarbon well and production data can be applied as a basis for informing abandonment, the variations and limitations of these data collections and organizations, which are readily apparent when looking at state-level data, need to be acknowledged. State-level data are a primary source of hydrocarbon well and production data. For example, consider an important difference between California and Texas. California (California Department of Conservation, 2024) releases well data using 11-digit unique well identifiers (UWIs) although Texas (Railroad Commission of Texas, 2023) uses 10-digit UWIs. This means that in California, it is possible to trace production back to a specific well bore, although in Texas, it is possible only to trace production back to the well's surface location. This means that when tracing the production of hydrocarbon wells across the United States, the most specific level of analysis is by surface location.

The methodology discussed in this report was needed as a way to identify abandoned oil and gas fields or formations amendable to the storage of natural gas or renewable energy to assist U.S. Geological Survey assessments of underground energy potential (U.S. Geological Survey, 2020). Through work for U.S. Geological Survey (USGS) projects, the authors have experience with various oil and gas data products and have learned about the limitations associated with this type of data. After reviewing decades of hydrocarbon data, the USGS was able to develop a data-driven approach by quantifying gaps in recorded hydrocarbon production with the goal of creating a definition of hydrocarbon well abandonment. Using this production-based definition for abandonment, we were able to identify wells that meet the definition's criteria. An additional benefit of identifying abandoned wells is that the inverse product is an active wells dataset, which has its own research value and use cases.

The following discussion consists of three sections. The "Data Considerations" section discusses the variability, limitations, and structure of hydrocarbon data. The "Data Considerations" section also provides background on U.S. hydrocarbon data and informs the reader of the availability and limitations of hydrocarbon data. The "Methodology" section analyzes the production gaps, defines hydrocarbon well abandonment, and describes the method for identifying abandoned wells from oil and gas data. The "Methodology" section also explains the process for creating a data-driven definition of hydrocarbon well abandonment using an analysis of monthly oil and gas production data from a proprietary database offered by S&P Global (2023). The "Summary and Conclusions" section describes a process for using the definition of hydrocarbon well abandonment to classify abandoned and active hydrocarbon well inventories from the same S&P Global proprietary database. The "Summary and Conclusions" section also describes the results, lists summary statistics, and provides use cases. Data on well classification could be useful for energy resource assessments, energy storage, and energy resource management.

Purpose and Scope

The USGS is tasked with assessing energy resources in the United States. This includes underground storage amendable to storage of natural gas or renewable energy such as compressed air. To make these assessments, the USGS needed a way to identify abandoned oil and gas wells. The purpose of this report is to define hydrocarbon well abandonment and, using the newly created definition, identify hydrocarbon wells. This report considers existing definitions and uses existing hydrocarbon production data in crafting a new definition of hydrocarbon well abandonment. Because we are defining hydrocarbon well abandonment, we are also able to define and identify active hydrocarbon wells by using the inverse of the definition for abandonment. Also, because abandoned and active hydrocarbon wells are being defined and identified, this methodology allows for the identification of abandonment at different spatial scales using ratios between abandoned and active wells. A Java program was created to identify abandoned hydrocarbon wells from an S&P Global U.S. hydrocarbon database (S&P Global, 2023). Because the U.S. hydrocarbon database is no longer offered by S&P Global, and because the potential user base would be very small, this report does not include the source code for the Java program. Instead, the process for using the newly created hydrocarbon well abandonment definition to identify abandoned wells from a hydrocarbon database is described.

Data Considerations

United States hydrocarbon data are created by operators, companies, States, and government entities. The organization of production records can vary between these data sources. For this reason, this report considers the ways these data sources differ, the limitations associated with these data, and methods for organizing hydrocarbon production data.

Variability of Data Sources

The differences in how individual wells can be identified was discussed in this report's "Introduction" section. Another example of variation can be found in well production data. Production data for a well listed as a single surface location may come from multiple underground formations or reservoirs at different depths, which is often referred to as comingled production. The level of detail at which this production is reported can vary between data sources. In some data sources, hydrocarbon production is reported as a single volume from an individual well; this is known as well-level production. Another way hydrocarbon production can be reported is as a single volume from multiple wells, which is known as lease-level production. The methodology developed in this study to classify wells relies on S&P Global's U.S. oil and gas Petroleum Information Data Model (PIDM) database (S&P Global, 2023; hereafter S&P Global's database), which contains lease- and well-level data through February 2023. PIDM is a database structure used by S&P Global's U.S. oil and gas database and is based upon the Public Petroleum Data Model association standards; the PIDM is no longer active.

Limitations of Recorded Data

Hydrocarbon production data records in the United States are highly variable because each State defines and regulates its own hydrocarbon exploration and extraction operations. Data collection may include regular reporting. Therefore, consistency and timeliness are the main limitations of state-level databases. For example, Illinois does not require hydrocarbon volume reporting (General Assembly of Illinois, 2023) at the well level, whereas Colorado collected

hydrocarbon volumes at lease levels before 1999 and has collected hydrocarbon volumes at the well level since 1999 (Colorado Oil and Gas Conservation Commission, 2002). Texas collects oil and gas volumes at the lease level but also collects enough well data such that S&P Global can allocate the oil and gas production down to the well level using a proprietary approach (Dick Catto and Bruce Smith, IHS Inc. [now S&P Global], written commun., 2014; Railroad Commission of Texas, 2024). Simply put, allocation allows S&P Global to take a single production volume from multiple wells and use associated lease and field-specific information to allocate the production volumes to the individual wells that composed the leave-level production volume.

Another limitation of hydrocarbon data records is consistency. State-specific reporting requirements create challenges when gathering all hydrocarbon production data across the United States. Some States require reporting of all hydrocarbons produced along with those injected, and other States only require a single hydrocarbon constituent (for example, oil but not natural gas) to be reported. Timing is also an issue because each State defines and manages its own hydrocarbon data reporting requirement, which can range from six months to as many as 2 years. Given that each State also typically has its own format and schedule for releasing available hydrocarbon production data, compiling data from all States into a single database can be challenging. Companies like S&P Global and Enverus provide comprehensive U.S. hydrocarbon production databases. Because these databases include publicly sourced and proprietary data and calculations, there are likely to be variations between these commercial data sources as well. Given these persistent limitations of the data, data sources, and the wide range of reporting requirements, this report takes a conservative approach to defining abandonment. For example, because the maximum time for an operator to report to the State is 2 years, our definition conservatively uses 5 years as the cutoff to avoid misidentifying wells.

United States Production Data

The methodology used in this study accounts for the variability of data sources and limitations in reported data while utilizing the proprietary data provided by S&P Global for U.S. well records and production data. At the time of this analysis (2024), S&P Global's database contained more than five million wells and almost three million production entities. The S&P Global database organizes well information using a 14-digit UWI, whereas their production information uses the producing "entity" and "entity type" as additional unique identifiers specifically for reporting volumes. The entity identifier is a combination of 2 to 23 alphanumeric characters that uniquely identify a specific record containing production volumes recorded through time. The entity type identifier indicates whether the production is recorded at the level of a lease, a well, or has been allocated (as previously explained). Because wells may produce hydrocarbons from multiple formations and because some States report their production by lease, there often exists a many-to-many relationship between well and production data.

S&P Global's database includes not only production but also injection volumes, which may contain data for fluids other than oil and gas that may be withdrawn or injected as part of the hydrocarbon extraction process. The methodology in this report only considers produced hydrocarbons when determining whether a well is active or abandoned. This precludes considerations for injection, water, and stratigraphic wells (exploration wells used to gather geologic information). There are research opportunities to modify the methodology to consider these wells when making the active or abandoned determination.

Methods

This report uses U.S. hydrocarbon data as a guide for defining hydrocarbon well abandonment by analyzing gaps in existing production data. Quantifying existing production gaps in U.S. hydrocarbon data allows for creating statistics about the duration and distribution of pauses in previous hydrocarbon production. Using the statistics on duration and distribution of gaps in production as a guide, we can create a definition for hydrocarbon well abandonment that excludes the wells whose production may be temporarily paused. After defining and analyzing hydrocarbon well abandonment, this report describes a process for using the newly created definition to identify active and abandoned wells from the same U.S. hydrocarbon data.

Analysis of Production Gaps

From a data-analysis perspective, the most common issue with using production data to classify a well as abandoned is the possibility of a short-term production pause (Seely, 2016). Hydrocarbon production is subject to market changes in supply and demand (Seely, 2016). Also, hydrocarbon production wells are mechanical operations and require periodic maintenance. Most, if not all, well maintenance requires the production operation to be halted while the maintenance is performed (Seely, 2016). Therefore, it is not uncommon for a well to pause production for economic or mechanical reasons.

For this study, it was essential to quantify these production pauses and their durations. To accomplish the goal of quantifying production pauses for millions of wells, a Java program was written that used the S&P Global PIDM production database to count production pauses and their durations. The program output specifying the produced fluid and the duration of the production pause allowed for analysis by duration and fluid. For example, a pause of one month for oil has a frequency of 1,832,874 occurrences in the database. Analysis was performed on individual hydrocarbon fluids (oil, gas, gas condensate, and casinghead gas) separately and all fluids together. Even though there is some variation

in frequency between these analyses, the percentages of frequency all follow the same decline trend. The trend shows at least 90 percent of the production gaps lasting 2 or fewer years, 96–98 percent of the gaps lasting 5 or fewer years, and 98–99 percent of the gaps lasting 10 or fewer years (fig. 1).

Given some of the limitations of the data, like variations among States and differences in the amount and type of data collected, we chose to be conservative in our definition and defined an abandoned well as a well that has not produced for 5 or more years. Most production pauses are 2 or fewer years, but given the limitations of the data, it was determined that 2 years could fall within the minimum time frame required by some States for data reporting. Additionally, using a gap of 10 years would capture almost all occurrences of inactivity but would miss many wells due to the lag time to reach 10 years for inclusion in a cutoff (for example, a well that had not produced for 6 years would be considered active because it had not been inactive for 10 years). Setting the threshold at 5 years accommodates long periods of inactivity while excluding records with short production gaps due to reporting, economic, or maintenance issues.

Definition of Well Abandonment

The methodology in this report does not use well attributes reported in the S&P Global database, like well status or production status, when defining well abandonment. Because data sources vary in how they define statuses, this methodology relies on production data as a starting place for defining hydrocarbon well abandonment. With quantified production gap frequency data on hand, the definition of well abandonment can be tailored using well data as a guide. For example, if a user has enough well data to quantify production gaps, then they could use their data to justify using production gaps greater than 2 years as indicating well abandonment instead of our use of greater than 5 years. This report uses the structure of the PIDM database to quantify production gaps because the database organizes production by entity, entity type, fluid, and year and includes production volumes for all months within each year recorded. This structure also allows well production to be classified as either well-level or lease-level production. Analyzing production gaps on a national scale permits a cutoff to be determined between production pauses and abandonment using the data as a guide. We define an abandoned well as a well with a spud date (the date when drilling operations begin for a new well) before January 1, 2021, that either has no associated production or has no production reported in the last 5 years.

This methodology only considers wells started 2 years before the most recent vintage of the hydrocarbon data because State reporting requirements vary across the United States, and not all States require 2 years for their data to become available. This results in two ways a well can be considered abandoned. First, if a well completed before January 1, 2021, has no associated recorded hydrocarbon production, it is considered abandoned. Second, if a well completed before January 1, 2021, has associated recorded hydrocarbon production (at the well or lease level) but has no reported production in the last 5 years, the well is considered abandoned.

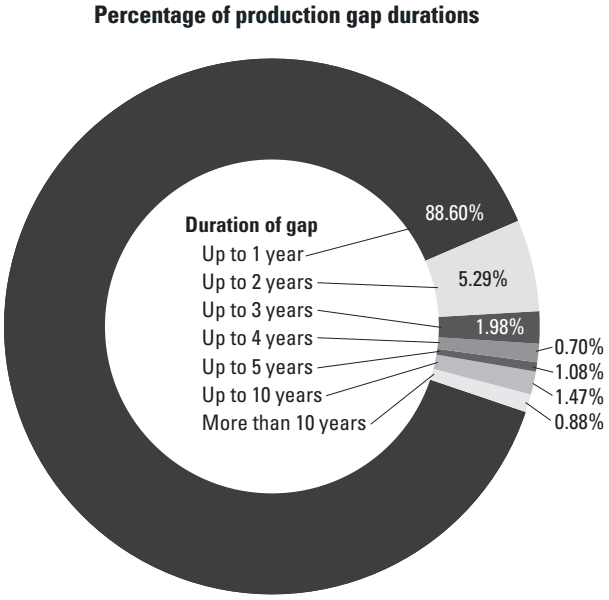

Figure 1. Pie chart of production gap duration yearly percentage increase for up to 1 year and up to 2, 3, 4, 5, 10, and more than 10 years.

Method for Identifying Abandoned Wells from Oil and Gas Data

In developing this methodology, a Java (Oracle, 2023) program was created to systematically query the proprietary S&P Global U.S. PIDM oil and gas database (which is no longer active) to identify abandoned and active wells using the abandonment definition described in the section of this report titled "Definition of Well Abandonment." Given the proprietary nature of the underlying database and the small potential userbase, this report does not include the data or the Java program code but describes the general steps taken by the program to identify active and abandoned wells. The S&P Global U.S. PIDM contains proprietary data restricting the release of raw data, which limits the usefulness of the Java code because only users with access to PIDM would be able to use the Java code. Also, S&P Global offers many different products related to U.S. oil and gas data, with PIDM being an older product. Only a small userbase would be able to utilize the Java code. However, the program is logically straightforward and easily recreated from figure 2, which is a flowchart of the steps in the methodology as described in the rest of this section.

The program starts by compiling, from the main well table, all UWIs not including the UWIs that have a spud date 2 years or less from the analysis date (February 2023). This

initial step creates a virtual list of all available unique wells stored within the larger database. Once all UWIs of interest have been compiled, the code then loops through all the UWIs and looks at each UWI individually. For each UWI, all associated producing entities are compiled. Because the production is organized separately from the well information, this step links the UWI to the associated production entities and determines if well or lease-level production is analyzed. If any of the production entities associated with the UWI has an entity type of "lease," lease production will be analyzed; otherwise, well production will be used. Once the type of production has been determined, the process continues by looping through the compiled entities. This loop allows the program to consider each producing entity associated with each UWI.

For each entity, the database is queried to determine which hydrocarbon fluids have been produced during the entity's lifetime. For each fluid the entity has produced, the production volumes for the previous 5 years are compiled. This step allows the program to compile all hydrocarbon volumes for the previous 5 years on a per fluid and per entity basis for each UWI. Each fluid is evaluated, and if all produced volumes for the past 5 years are empty or zero, the program marks the fluid as "not present" and progresses to analyze the next fluid. If any of the production volumes are greater than zero for any of the previous 5 years, the program marks the fluid as "present" and progresses to the next fluid. This step permits all entities and fluids to be checked individually and a decision made regarding whether production is present or not.

After all hydrocarbon fluids have been analyzed, if all fluids are marked as "not present," the entity is marked as "abandoned." If any of the hydrocarbon fluids are marked as "present," the entity is marked as "active." This programming step decides whether a unique entity associated with a unique UWI is considered abandoned or active by analyzing all hydrocarbon fluids associated with the unique entity. Once all the entities associated with a UWI have been analyzed, if all entities are marked as "abandoned," the UWI is considered abandoned. If any of the entities are marked as "active," the UWI is considered active. This is the final determination for each UWI whether the well is considered active or abandoned. Once all the millions of UWIs have been classified as either active or abandoned, the program is almost complete. The final step is to write the data to two separate files, one file containing the abandoned well information, and the other containing the active well information. As of the date of analysis (February 2023), one file contained more than three million abandoned records, and the other file contained more than one million active records.

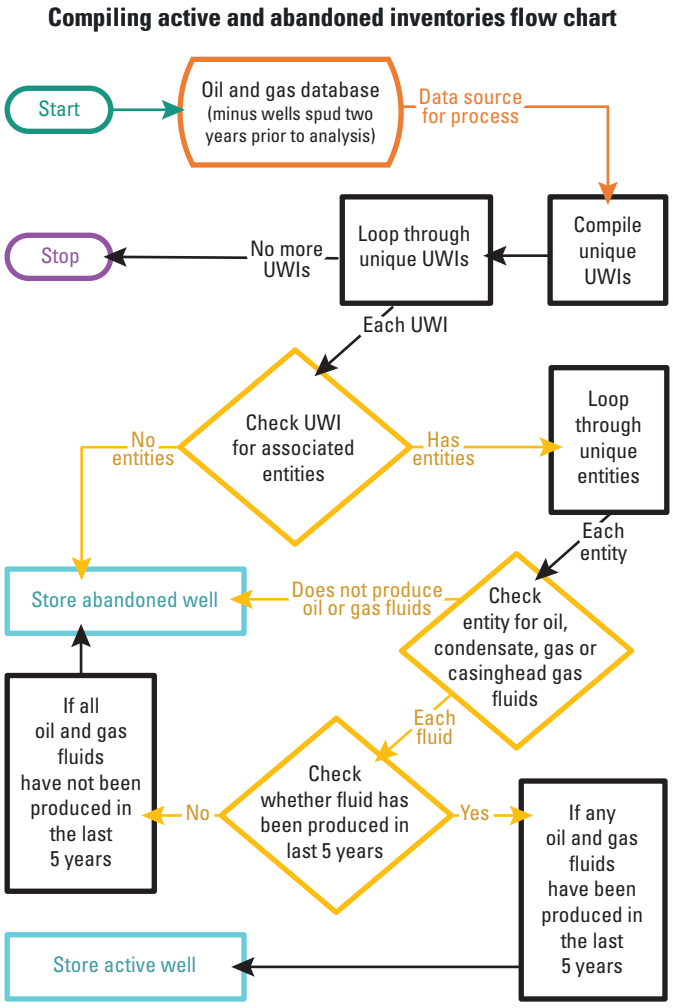

Figure 2. Flow chart of method for compiling active and abandoned well inventories. UWI, unique well identifier; entity, unique production identifier. A UWI can have multiple entities.

Summary and Conclusions

After reviewing existing terms, definitions, and research on the abandonment of hydrocarbon production wells, we found that abandonment is not easily defined. There are many terms that describe the same basic idea, including "abandoned," "orphan," "plugged and abandoned," "temporarily abandoned," and "nonproducing." These terms are meant to identify inactive wells but differ in the status of that inactivity. Additionally, most existing publications and definitions are specific, legally defining abandonment or focusing on specific aspects of abandonment. These existing definitions and publications are focused on aspects of abandonment and use one or some of the existing terms to identify abandonment. In contrast, this method uses hydrocarbon production records in a data-driven approach to create a definition of abandonment based on analysis of production pauses and a method for identifying these wells.

Because production data have variability in their sources and limitations in how the data are recorded, particularly at the State level, data from the S&P Global database were used for this report. There may be valid reasons for a producing well to be temporarily inactive, so it was necessary to quantify and analyze periods of inactivity using S&P Global U.S. oil

and gas production records. Although 89 percent of inactive periods were 1 year or less, this may be due to some States allowing operators as many as 24 months to report production. Additionally, the data showed that the percentage of inactivity ranged from 84 percent of the occurrences of inactivity for periods of 12 or fewer months to 99 percent for periods of 120 or fewer months.

After analyzing the frequency of inactive periods and given the variability and limitations associated with hydrocarbon production data, along with the varied reporting requirements, the methodology in this report uses a conservative 60 months (5 years) of inactivity as the threshold between active and abandoned production to account for 96 percent of periods of previous inactivity in production. This methodology also considers new wells that may not have reported production at the time of analysis. This report therefore defines abandonment as a well spud at least 24 months (2 years) prior to analysis that had no oil, gas, condensate, or casinghead gas (hydrocarbon) production or lacked any hydrocarbon production for the previous 5 years. In addition to creating a technical definition for hydrocarbon well abandonment, this report describes a process for applying this definition to classify wells within the S&P Global U.S. oil and gas database as either active or abandoned.

This methodology was developed to assist the U.S. Geological Survey's assessments of underground energy storage potential. The U.S. Geological Survey needed a way to identify abandoned oil and gas fields or formations amendable to storage of natural gas or renewable energy such as compressed air. This methodology allows for the identification of abandonment at different spatial scales using ratios between abandoned and active wells. Comparing the number of abandoned wells to the number of active wells can indicate the level of current activity and can illuminate abandoned areas or areas with low activity within the United States.

Potential uses for this methodology outside the U.S. Geological Survey include recreating this process with user-supplied data. Alternatively, if a user has access to the S&P Global U.S. oil and gas database, a user could recreate the same datasets described by this methodology. Using the flowchart and description provided herein, a user could take data that have associated production volumes, if the data are provided by individual States or a commercial hydrocarbon database and create a program to categorize wells. The resulting datasets created by this methodology have uses in energy storage, hydrocarbon resource assessments, and natural resource management.

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