April 11, 2022

Assessing Methane Emissions from Orphaned Wells to meet Reporting Requirements of the 2021 Infrastructure Investment and Jobs Act (BIL):
Federal Program Guidelines

About these Guidelines

These Guidelines were developed to meet the federal program reporting requirements for methane emissions reductions as described in Section 40601 (Orphaned well site plugging, remediation, and restoration) of Title V (Methane Reduction Infrastructure) of the 2021 Bipartisan Infrastructure Law (BIL; Public Law 117-58).

The Guidelines have five parts:

PART I. BACKGROUND INFORMATION. Including BIL reporting requirements; characteristics of methane emissions from orphaned wells; and the methods and challenges of measuring, modeling, and documenting methane emissions from orphaned wells.

PART II. FLOWCHART. For visualizing decision-making points for methane measurement.

PART III. OPTIONAL SCREENING PROTOCOL. Methodologies to assign wells to 'non-detect', 'detect', and 'detect + may be high' categories to aid prioritization of wells for plugging.

PART VI. MAIN PROTOCOL: METHANE EMISSIONS RATE MEASUREMENT. Methodologies for estimating methane emissions reductions achieved by well plugging to meet BIL reporting requirements and support national inventory emissions modeling efforts.

PART V. REFERENCES. References cited and additional references detailing current best practices and protocols.

Rather than prescribe specific approaches for detecting and measuring methane, the Guidelines recommend data measurement objectives and quality assurance criteria that will meet federal program information needs for methane measurements and allow for aggregation.

Although certain technologies and methods are mentioned, they are for informational purposes only. No endorsement is made by the U.S. Government for any specific equipment, device, technology, or method, any private company, non-profit entity, or public organization. The U.S. Government is committed to contracting processes that follow all relevant laws, rules, and regulations.

Guidelines Preparation and Authorship

These guidelines were researched, discussed, and prepared by an interagency team that met from August 2021 through March 2022.

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PART I. BACKGROUND INFORMATION

Synopsis: Information Provided and Purpose of Part I

Part I of the Guidelines provides background information by explaining the methane reporting requirements of the BIL Title V, Sect. 40601; the characteristics of methane emissions from orphaned wells; and the methods and challenges of measuring, modeling, and documenting methane emissions from orphaned wells.

Why Plug Orphaned Wells?

Orphaned wells, either unplugged or improperly plugged, can:

- Emit methane, a potent greenhouse gas, and other harmful gases into the atmosphere such as aromatic hydrocarbons (benzene, toluene, ethylbenzene, xylene (BTEX)), various volatile alkanes, and hydrogen sulfides,
- Leach contaminants, gas, and oil into surrounding soils and waters, and
- Create safety hazards that prevent lands from being used for recreation or other productive purposes.

Addressing the safety risks, climate forcing, and other environmental harms caused by orphaned wells requires the cooperation and collaboration of numerous agencies across the whole of government.

Current National Statistics: Well Count, Location, Emissions

There are an estimated 3.5 million abandoned oil and gas wells in the U.S., including plugged (~39%), orphaned, and inactive wells (data not disaggregated; 1990-2020 Draft Inventory of Greenhouse Gas Sources and Sinks; US EPA (2022)).

U.S. abandoned wells are concentrated in Appalachia and the Midwest, the Gulf and Central states, the Rocky Mountains, and California, with the majority occurring in four states: TX, PA, KS, and WV (**FIG. 1**).

In 2019, fugitive U.S. methane emissions from abandoned wells had an estimated thermal energy value of 284 kilotons—equivalent to 7.1 million metric tons (MMT) of CO_2 with a 95% confidence interval of 1.1 to 20.8 MMT, the highest uncertainty among the nation's largest sources of methane (US EPA 2021).

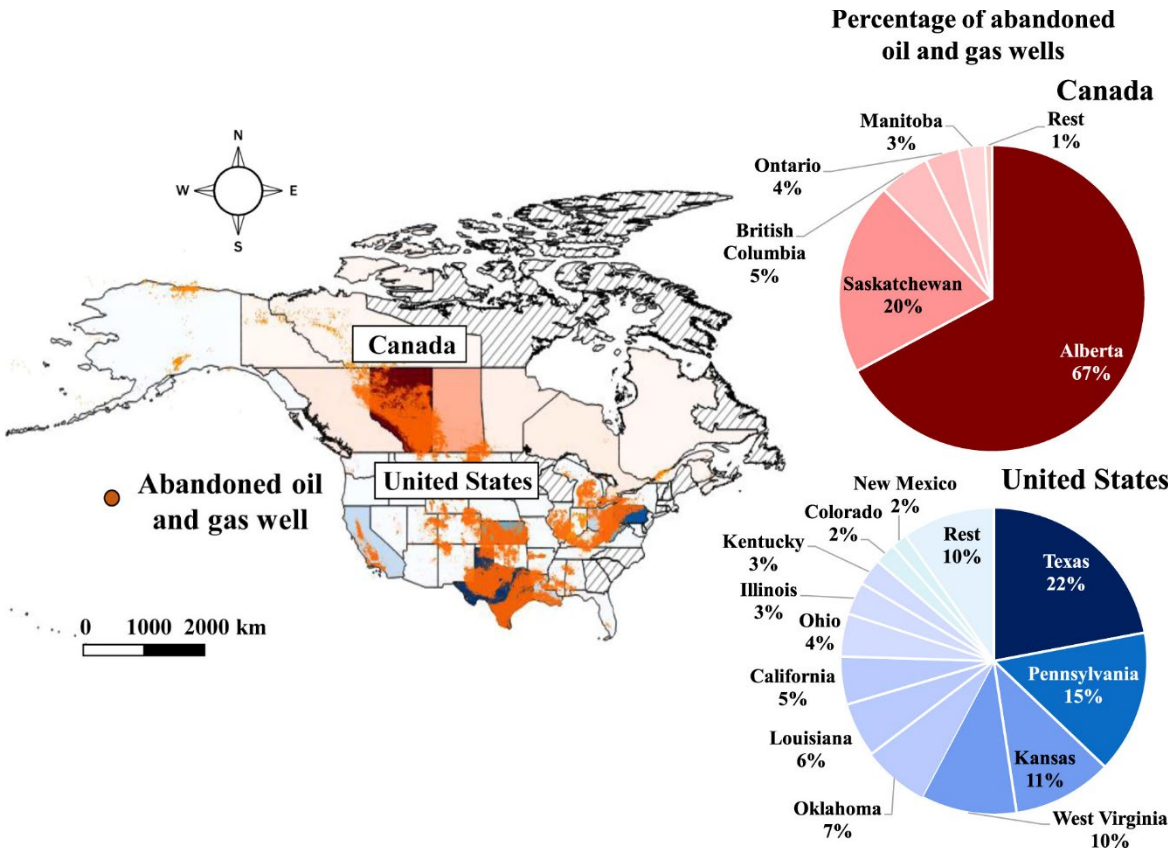


FIG. 1. MAP OF ALL ACTIVE AND ABANDONED OIL AND GAS ONSHORE WELL LOCATIONS (LEFT) GATHERED FROM PUBLICLY AVAILABLE DATABASES FOR THE US AND CANADA. PIE CHARTS(RIGHT) SHOW PERCENTAGES OF WELLS IN EACH STATE/PROVINCE/TERRITORY RELATIVE TO THOSE ACROSS THE COUNTRY. STATES/PROVINCES/TERRITORIES IN THE MAP AND THE PIE CHARTS ARE PRESENTED USING THE SAME COLOR SCHEME. FROM WILLIAMS ET AL. 2021. REPRINTED WITH PERMISSION FROM ENV. SCI. TECH. 55(1),563-570. COPYRIGHT 2021 AMERICAN CHEMICAL SOCIETY.

About the Bipartisan Infrastructure Law (BIL)

The BIL, a once-in-a-generation investment in our Nation's infrastructure and competitiveness, was signed into law on November 15, 2021. Among its many goals are tackling the climate crisis, advancing environmental justice, and investing in communities that have too often been left behind. To help achieve these goals, the BIL established the Title VI, Section 40601, Orphaned Well Program which includes a federal program for addressing orphaned wells on federal land and a grant program for states and tribes to establish or enhance and manage their own orphaned well plugging, remediation, and restoration programs on State, private, and Tribal lands. Activities under this section must be reported annually to Congress, as follows:

> *(f) REPORT TO CONGRESS.—Not later than 1 year after the date of enactment of the Infrastructure Investment and Jobs Act, and not less frequently than annually thereafter, the Secretary shall submit to the Committees on Appropriations and Energy and Natural Resources of the Senate and the Committees on Appropriations and Natural Resources of the House of Representatives a report describing the program established and grants awarded under this section, including—*
>
> > *(1) an updated inventory of wells located on Federal land, Tribal land, and State and private land that are—*

(A) orphaned wells; or
(B) at risk of becoming orphaned wells;
(2) an estimate of the quantities of—
(A) methane and other gasses [sic] *emitted from orphaned wells; and*
(B) emissions reduced as a result of plugging, remediating, and reclaiming orphaned wells

Part IV of this guidance document is designed to meet the reporting requirements for (f)(2)(B), 'emissions reduced as a result of plugging, remediating, and reclaiming orphaned wells. That is, Part IV explains how to measure methane emissions rates that can be aggregated for annual reporting. Data collected following these guidelines will also support (f)(2)(A) by adding to the national inventory of directly measured methane emissions rates and by helping to reduce uncertainties in national estimates of well counts and emissions factors.

Instrumentation Used to Measure Methane

Instrumentation used to measure fugitive methane from the oil and gas sector can be divided into three groups: satellite, aerial, and ground-based. The main difference between the groups is their sensitivity and this dictates their applications.

- **Satellite-mounted sensors**, such as GHGSat and TROPOMI, are typically focused on global and regional areas. High earth-orbit satellite-mounted sensors measure fugitive methane emissions in the *metric tons per hou*r range (1 metric ton = 1000 kilograms: 1 kilogram = 1000 grams) whereas low earth-orbit sensors can be slightly more sensitive (0.1-0.2 metric tons/hour).
- **Aerial technologies**, such as unmanned aerial vehicles (UAV) and airplanes coupled with various sensors, typically measure methane emissions in the *100 – 1,000 kilograms per hour range* and may be more appropriate for active oil and gas production sites with many potential leak sources. This sensitivity can be increased to as low as 0.5 kg/hour in close proximity to a source. Both satellite and aerial approaches utilize spectrometry and meteorological data to estimate methane emissions.
- **Ground-based techniques**, such as hand-held natural gas detectors, high-flow samplers, and flux chambers, are direct-emission measurement techniques that require an individual to be present at the well site. These techniques are capable of detecting methane emissions at leak rates *of 1 gram per hour or lower*, making them suitable for orphaned well sites.

Understanding Methane Concentration versus Rate

It is important to delineate the difference between detecting concentrations and quantifying emission rates. Some handheld devices, such as gas sniffers, are utilized to detect the presence of gases and can be configured for combustible gases and/or other gases of interest. While inexpensive, the precision of these devices is highly dependent on weather conditions and the number of leaks at a site. Further, these instruments provide **gas concentrations**, such as parts per million or percent volume, which is distinctly different from an **emissions rate**. A rate requires both a concentration measurement and a flow measurement. A simple equation is shown below:

$$\dot{V}_{methane} = C_{methane} * \dot{V}$$

where $\dot{V}_{methane}$ is the methane-specific flow rate from the orphaned well, $C_{methane}$ is the measured concentration of methane from the orphaned well, and $\dot{V}$ is the total flow measured from the orphaned well. Other handheld devices, such as optical gas imaging (OGI) cameras, are expensive and typically do not provide a concentration or flow rate, though algorithms are being refined to do so. OGI cameras are primarily designed for visualizing leaks from oil and gas infrastructure, limiting their use to detecting the presence or absence of gas.

Emissions rates are measured using high volume samplers, static and dynamic chambers, and combinations of various techniques (See Part V. References). Due to the rapidly changing nature of technology and methods for measuring methane leaking from orphaned wells, the methane emissions rate protocol (Part IV) intentionally allows for novel approaches so long as they meet the requirements outlined therein.

‘Other Gasses’

The BIL does not provide further specification regarding the “other gasses” mentioned in Section 40601(f)(2)(A) above. Differentiating and quantifying all the gases emitted from a well is expensive and time consuming. It is either conducted in a laboratory setting using grab samples or in the field using expensive and fragile portable spectrometers. Collecting grab samples in the field is challenging and requires separate training and equipment. One approach that may satisfy this requirement would be to measures total hydrocarbons in addition to measuring methane independently. This would provide a measurement of most of the other gases, although it would neither speciate nor quantify the individual gaseous organic compounds. Other gases can include alkanes such as ethane, propane, isobutane, n-butane, isopentane, and n-pentane and aromatic hydrocarbons like benzene, toluene, ethylbenzene, and xylene. Concentrations of these individual gases are generally minute compared to methane.

Hydrogen sulfide (H_2S) is present in some oil and gas basins and may not be detected in others. Limited evidence from a study of 63 abandoned, marginal, and active wells in Ontario, Canada, suggests that H_2S emissions will most likely be detected among abandoned wells where methane emissions rates are > 1 gram/ hour (El Hachem & Kang 2022).

Concentrations (but not emission rates) of H_2S can be measured using hand-held equipment or wearable badges. Although H_2S could fall in the reporting category of “other gasses”, concentration measurements are typically conducted only for reasons of personnel safety. If H_2S is high enough to detect by smell, then high levels of caution are warranted, and the well should only be approached with adequate personal protective equipment (PPE) and other protective procedures in place. Olfactory fatigue can make odor detection by smell ineffective and this can be dangerous in locations with high concentrations of H_2S especially if safety precautions are not in place.

For now, the recommended method for estimating (not measuring) "other gasses" is to use geographically specific oil and gas profiles (emission factors) that provide an average fractional percentage of different gases in the gas stream for each specific basin. This method may need to account for differences between oil wells and natural gas wells that occur in the same geographical basin as the two types of wells can have different fractional proportions of gases. At this point it is unknown how many basins and wells will need to be measured to derive emissions factors that have acceptable ranges of uncertainty. The composition of other gases would also depend on the age of the wells and the density of the components and could vary within the basin. The emissions factors and the protocols recommended in these Guidelines can be improved as more data is gathered.

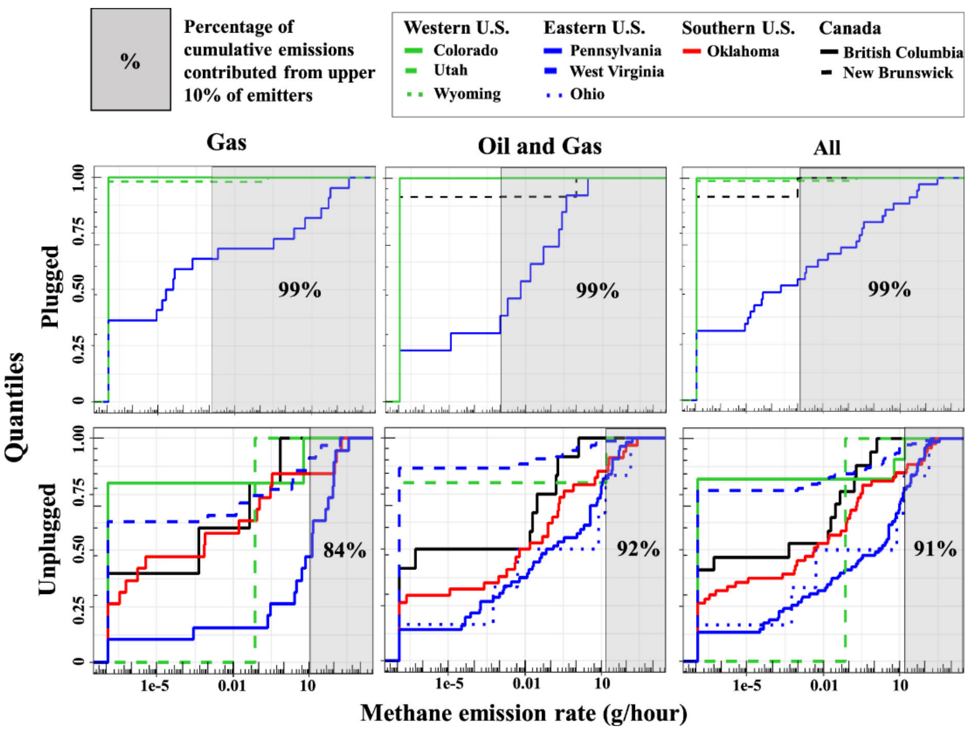


FIGURE 2. EMPIRICAL CUMULATIVE DISTRIBUTIONS OF MEASURED METHANE FLOW RATE FROM PLUGGED (TOP) AND UNPLUGGED (BOTTOM) ABANDONED OIL AND GAS WELLS IN THE US AND CANADA. EACH CURVE REPRESENTS A STATE/PROVINCE. BLUE AND GREEN CURVES REPRESENT EASTERN AND WESTERN STATES IN THE US. RED CURVES REPRESENT OKLAHOMA. BLACK CURVES REPRESENT CANADIAN PROVINCES. SHADED REGIONS IN EACH PLOT REPRESENT THE 90-100TH PERCENTILE OF METHANE EMISSIONS RATES FOR THAT GROUP, WITH THE ANNOTATION SHOWING THE PERCENTAGE OF CUMULATIVE EMISSIONS, THE TOP 10% OF ABANDONED OIL AND GAS WELLS. (REPRINTED WITH PERMISSION FROM WILLIAMS ET AL. 2021, ENV.SCI.TECH. 55(1) 563-570. COPYRIGHT AMERICAN CHEMICAL SOCIETY.

Anticipated Distribution of Methane Emissions among Orphaned Wells

Total emissions and emissions factors estimated to date for methane have been governed by high emitters (KANG ET AL. 2014, RIDDICK ET AL. 2019, WILLIAMS ET AL. 2021). In a study of 568 abandoned wells in the US states of OH, WY, UT, CO, PA, and WV, and Canadian provinces of NB and BC, Williams et al (2021) reported methane emission rates ranging from 1.8×10^{-3} grams/hour to 48 grams/hour per well depending on the plugging status, well type, and region, with the overall average at 6.0 grams/hour. Abandoned wells in the top 10% of emissions rates (i.e., >10 grams/hour) emitted 91% of the emissions (**Fig. 2**). If these distributions are typical, it is anticipated that using the detection limit of 1 gram/hour recommended in these Guidelines (Parts III and IV), most orphaned wells on federal lands will be non-detects, but the highest emitting wells and more than 90% of the total emissions will be captured.

Variability in Well Emissions Measurements

The study of emissions variability from orphaned and abandoned wells is an active area of research. The Guideline protocols (Parts III and IV) balance accuracy and precision for economy of scale. Sources of variability in methane emissions include:

Seasonal influences. The emission of methane and other hydrocarbons from orphaned wells may be seasonally influenced in some geographic locations or conditions. For example, shallow coal bed methane formations may not appear to have emissions when the groundwater level is higher, such as during spring recharge. Soil emissions rates can also vary due to soil moisture and the periodic build-up and release of emissions (**Fig. 4**). Wells that leak gas partially or fully into soil or an unsaturated zone likely have their emissions attenuated significantly by oxidation (Schout et al. 2018). However, detectable soil emissions are anticipated at relatively few sites. See Methane emissions from soils, below.

Weather conditions. Wind speed, wind direction, ambient temperature, the background temperature relative to the gas, soil moisture, humidity, and recent rainfall may or may not affect measurements. Measurements should not be made under high wind, or extreme temperature conditions, or during precipitation events. A qualified measurement specialist will know the appropriate range of weather conditions for measurements and how to obtain measurements under variable conditions.

24-hour variability. Recent work by Riddick et al. (2020) demonstrated five patterns of minute - to-minute variability across a 24-hour period of about 26-50%. The screening (Part III) and main methane rate measurement (Part IV) protocols set a precision data quality objective of 30%, which is within the same order of precision while avoiding more costly time series measurements.

Measurement system variation. The Part III and Part IV protocols call for a precision of 30%, but higher precision is possible with many measurement instruments.

The measurement specialist. If the appropriate methane measurement equipment has been selected for given well conditions and emissions rates and weather conditions are within operating specifications, the greatest source of variability, or error, in field measurements is anticipated to be the individual making the measurements. Hence the importance of assigning methane emissions rates measurements to a qualified measurement specialist.

Year to year variability. This is an area of active research, but from what is known, methane emissions from orphaned wells can be expected to continue for multiple years and possibly decades (Kang et al. 2016).

Types of Methane Leaks from Orphaned Wells

The types of leaks that can occur at orphaned wells are illustrated in **FIG. 3** below. Methane leaks may occur at

1. **The open well hole only**
2. **The open well hole and soils around the well hole** due to subsurface fractures in the well bore,
3. **Multiple valves, connectors, or cracks** at the legacy well head or other infrastructure associated with the well.

4a. T**he soil instead of the well opening**,

4b. **The well opening after a heavy rainfall event or after snowmelt** in spring when the groundwater forces methane that has permeated into the soil back into the well hole.

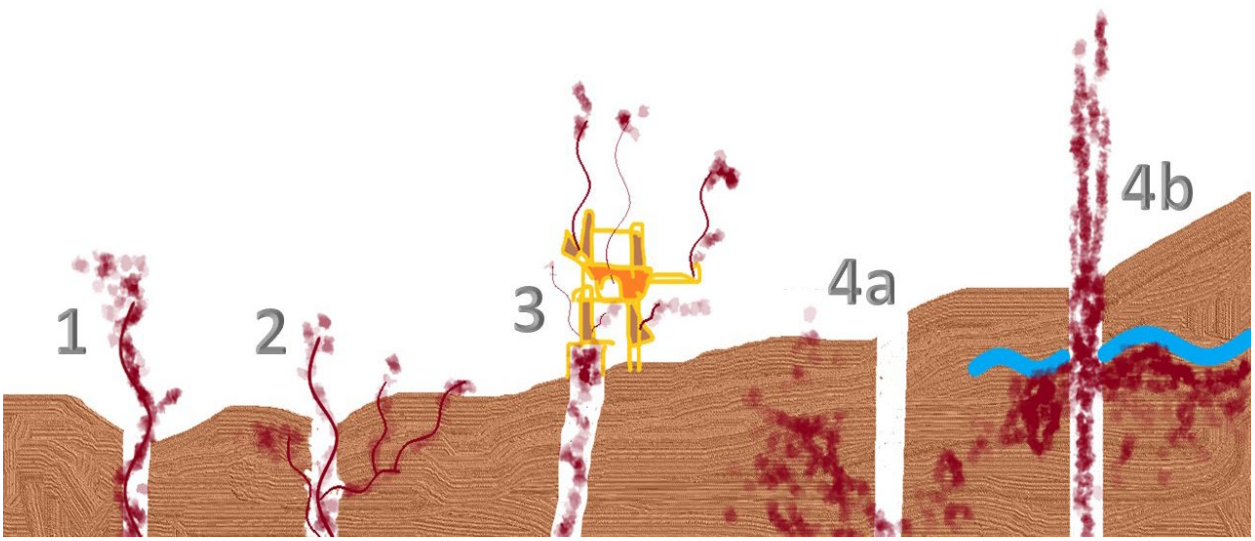


FIG. 5. TYPES OF METHANE LEAKS FROM AN OIL AND GAS WELL. SEE TEXT ABOVE FOR KEY TO TYPES. ILLUSTRATION BY JEFF SORKIN, USDA-FOREST SERVICE.

Methane Emissions from Soils

Emissions from well pad soils exceeding natural background can be caused by volatilization of liquid hydrocarbons spilled on the soil or, more frequently, failure of subsurface infrastructure (LYMAN 2022), including:

(1) **Cement failure** resulting from age-related deterioration or inappropriate cement density, inadequately cleaned boreholes, premature gelation, cement fluid loss, high permeability, shrinkage, radial cracking because of pressure changes, or poor bonding with rock or casing,

(2) **Casing failure** caused by leaking joints, casing collapse, or corrosion.

It is anticipated that methane emissions from soils will form a very low percentage of methane emissions from orphaned wells on federal lands. Lyman et al. (2022) calculated soils of inactive well pads in the Uinta Basin of Utah contributed only 0.0021% of the methane and 0.00029 % of the other non-methane, alkane hydrocarbons (NMHCs) emissions from all oil and gas-related sources in the Uinta Basin. They reported a heavy tailed distribution of soil methane and non-methane alkane hydrocarbons (other gases) among wells. That is, a small number of wells were the source of most of the emissions. These researchers also noted a logarithmic decline in soil methane and NMHC emissions rates with distance from the well head. (**FIG. 5**)

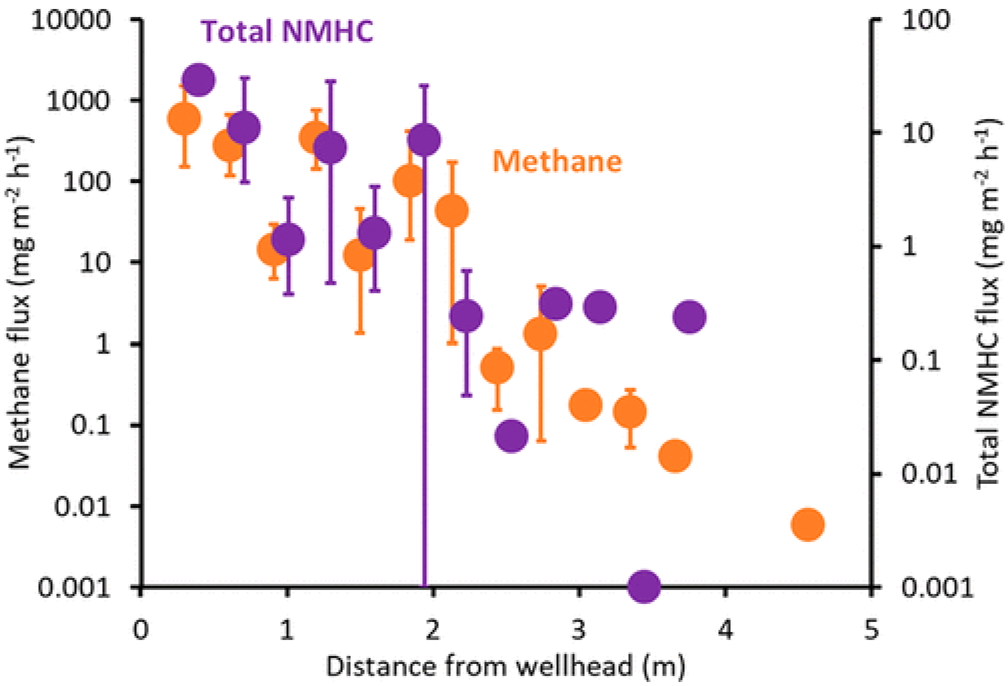


FIG. 5. AVERAGE SOIL METHANE AND TOTAL NON-METHANE, ALKANE HYDROCARBON (NMHC) EMISSIONS WITH DISTANCE FROM THE WELLHEAD AMONG 31 ACTIVE AND INACTIVE WELLS IN THE UINTA BASIN, UT. WHISKERS REPRESENT 90% CONFIDENCE LIMITS. Y AXES ARE IN LOG SCALE AND ARE DIFFERENT FOR METHANE AND NMHCS (FROM LYMAN 2022; 1000 MG M-2 H-1 = 1 GRAM/SQUARE METER/HOUR. REPRINTED WITH PERMISSION FROM ENVIRON. SCI. TECHNOL. 2017, 51, 20, 11625–11633. COPYRIGHT 2017 AMERICAN CHEMICAL SOCIETY.

Modeling Methane Emissions

Until additional ground-verified data are collected, the total national emissions estimate for the national inventory of orphaned wells for (f)(2)(A) will continue to rely on information from the Inventory of US Greenhouse Gas Emissions and Sinks estimate for *abandoned* wells. This inventory is submitted annually by the U.S. EPA to the United Nations (UN) to meet US commitments under the UN Framework Convention on Climate Change (e.g., US EPA 2022). Abandoned wells include plugged wells, orphaned wells, and inactive wells that are not plugged; the inventory does not report on orphaned wells separately. While methane emissions from abandoned wells are estimated to be among the top 10-12 largest sources of methane in the US, the total national estimate has a wider uncertainty range than any of the major methane sources inventoried by the EPA. This is caused by uncertainties in:

- **Well count**. The number of abandoned wells in the US is currently estimated at 3.5 million (US EPA 2022). However, both Kang et al. (2016) and Riddick et al. (2019) show that regional databases for PA and WV are likely underestimating well counts by a factor of ten.
- **Methane emissions factors**. The emissions factors used for the most recent national inventory (US EPA 2022) are derived from rate data measured by Kang et al. (2016) and Townsend-Small (2016) at <200 wells. This corresponds to <0.005% of the estimated count of US wells. Williams et al. (2021) reported emissions factors from 598 measurements, significantly reducing uncertainty in that study's estimate compared with previous estimates, though it is still very large compared to other top methane sources.
- **Variability in methane emissions across geographic regions**. Emissions factors used in the most recent national inventory (US EPA 2022) are derived from wells in PA, OH, UT, CO, and WY. Williams et al. (2022) conducted measurements from one more state, OK. Emissions factors are not yet available from some states/regions with very large well counts, e.g., TX, KS, LA.

To improve modeled estimates, it is recommended that agencies conduct field-based emissions measurements at a variety of representative oil and gas basins and well types. Using statistical estimation techniques and/or the development of geographically specific emissions models, these on-site measurement data would help to inform and evaluate emissions models that could better support future emissions inventory reporting required by the BIL.

In the future, emissions data could potentially be used in models to estimate reductions in methane from orphaned wells, reducing or eliminating the need to quantify gases at each well. The complete emissions dataset could then be used along with the orphaned wells inventory to develop the annual report to Congress.

Rationale and Applications of the Screening Protocol

Background Information and Context

Some estimates suggest there could be tens of thousands of undocumented and un-located orphaned wells just on U.S. Forest Service-managed lands in the eastern U.S. Nationwide, most orphaned wells are not documented and will need to be located and screened for fugitive emissions and other variables in order to prioritize wells for plugging.

Current studies suggest that there will be a wide range of emissions among orphaned wells, with most emitting no measurable or very low quantities of gas (< 1 gram/hour). It is anticipated that the minority of wells emitting > 1 gram/hour will be the source of the great majority of emissions. Among these, the very highest emitters will have a disproportionately high percentage of the total emissions. These wells are referred to as 'high emitters' in these guidelines. Pre-classification into one of three categories (emissions 'not detected', 'detected', or ‘detected + may be high’) can help decision-makers to prioritize wells for plugging based on anticipated relative methane emissions.

Instances when the screening protocol may not be valuable

The screening protocol for methane emissions classification may not be helpful if it is already known that:

- Methane emissions from the well will not be a driving factor in prioritizing it for plugging and remediation. For example, plugging the well will be prioritized regardless of other factors because it poses an unacceptable safety hazard or liability to the agency. [Follow the main methane quantification protocol.]

- The uncertainty of the classification will be too high to differentiate detects from non-detects due to seasonal variability in methane leaks from the specific basin. For example, prior experience within a particular geographic area may have revealed that at certain times of year, a well in a given basin can be a ‘non-detect’ while at other times it is believed to be a high emitter. [Follow the main methane quantification protocol at an appropriate time of year.]

- Classifying methane emissions during well location and inventory efforts provides no significant cost savings or increase in emissions reductions over quantifying emissions prior to well plugging. For example, the agency plans to close all the orphaned wells that it locates. [Follow the main methane quantification protocol.]

- The wells are already located or identified for plugging and remediation. [Follow the main methane quantification protocol.]

Definition of Qualified Measurement Specialist

A measurement specialist refers to the contractor, partner, or agency employee who will be conducting methane measurements at the site for methane (and ‘other gases’ if required by the agency). A ‘qualified measurement specialist’ will have training and field experience with the specific equipment and methods that have been proposed and approved by the agency for use at the targeted well sites. ‘Sufficient’ means that the individual can make measurements that meet the data quality objectives of these protocols. At least one qualified emissions measurement specialist will be needed to quantify methane prior to plugging and remediating a well. The measurement specialist should not only be proficient at using gas measurement instrumentation, but also able to recognize and avoid/mitigate safety hazards related to the oil and gas well, field conditions, weather variables, etc., to maintain personal safety. Ideally the measurement specialist will have 20+ hours of training and experience with the specific equipment type and/or methods.

Measurement specialists should be aware of the key variables affecting emission measurements from orphaned wells. Emissions from orphaned wells are typically lower than those of producing wells and differ in other ways such as age, condition, and type of legacy infrastructure. Therefore, detection and measurement at orphaned wells requires specific knowledge and training. Measurement specialists should be familiar with the reference documents provides in these guidelines, particularly those relevant to specific measurement instrumentation they are using. The specialist should understand how the above factors affect methane detection and measurement. For example, high wind speeds can quickly dilute methane concentrations; therefore, the qualified measurement specialist should be experienced with the performance of the measuring instrument used and the range of wind conditions over which it can provide repeatable data and only conduct measurements when wind conditions are within that range. The qualified measurement specialist should be prepared to submit data and results in a format that can be easily incorporated into the relevant agency database tool to assure consistent reporting.

Measurement Methods Documentation

The quantification (flow rate + concentration) methodologies and approaches employed by measurement specialists will be documented and submitted to the relevant agency to allow for adaptive management and to better define performance metrics. If the screening protocol is used by the qualified measurement specialist to classify wells into non detect, detect, or detect + may be high categories, this will also be documented and submitted to the relevant agency. The documentation needed is specified in the protocols (Parts III and IV of these guidelines).

Database and Database Interfaces

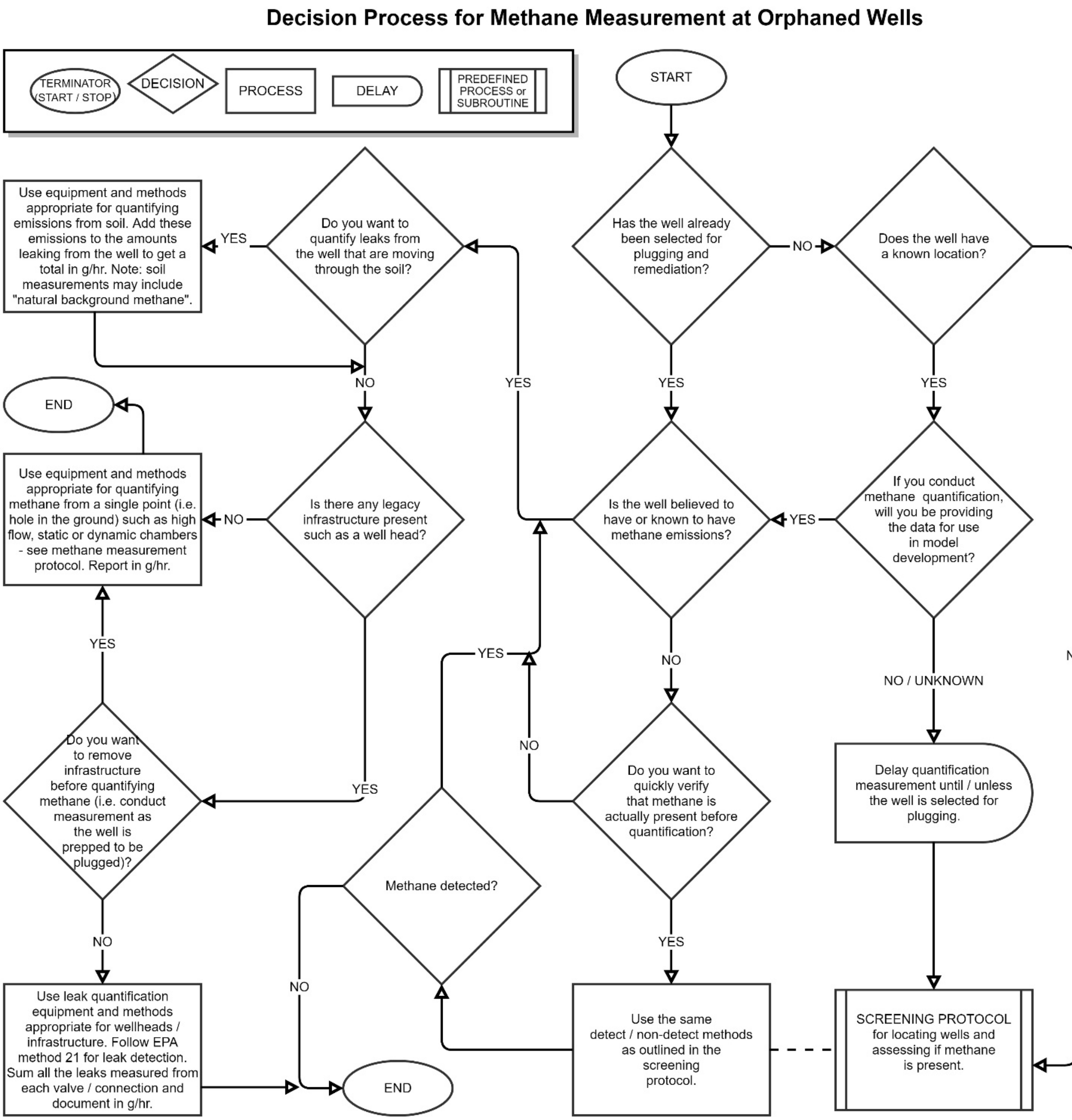
Agencies should develop a simple and easy to use database with a data input interface to aid the user or measurement specialist with recording data and information in a consistent format. The database should include a list of wells for conducting emissions detection and quantification assessments. It should also include an option for a specialist to enter data for newly discovered wells during field search efforts. The database input tool will prompt the person entering the data for the variables described in the "data collection requirement" sections below.

Adaptive Management

As more comprehensive information becomes available, this protocol will be improved and updated, including periodic:

a. Re-assessment of the protocol and optimization of workflow;
b. Review and inclusion of suggested modifications to protocols as submitted to the relevant agency by a measurement specialist; and
c. Review of emissions datasets to determine whether an emissions model can be developed for wells where measurement data is unavailable. Models may need to be specific to a geographic area, formation, or basin and consider geology, well age, depth, and type.

PART II. FLOWCHART. DECISION PROCESS FOR METHANE MEASUREMENT AT ORPHANED WELLS



PART III. OPTIONAL SCREENING PROTOCOL FOR DETECTING AND CLASSIFYING METHANE EMISSIONS

Synopsis: Information Provided by this Protocol

This protocol is designed to classify methane emissions from a well into one of three categories:

1. **Not detected.** Emissions are not higher than background levels.
2. **Detected.** Emissions are higher than background levels.
3. **Detected and may be high**. Emissions are higher than background levels and any one of five qualifying criteria are present that indicate emissions rates may be high.

Synopsis: Intended Applications of this Protocol

The information obtained from the protocol can facilitate the following processes.

1. **To acquire methane information inexpensively and efficiently while other inventory information is being collected to prioritize plugging of orphaned wells.** The protocol provides an efficient and economical means, suitable for most field sites (remote or easily accessible). These methods can be conducted by field personnel charged with finding and/or assessing orphaned wells. Several options exist for devices that are lightweight, fit in a backpack, and are hardy enough to endure field conditions. This includes long days of foot travel to explore remote, heavily vegetated sites during the well discovery process**.** Field personnel can be trained in their use pre-season. This method may be particularly time- and cost-saving in areas where many dozens or hundreds of orphaned wells are believed to exist and crews are already funded to find and assess them.
2. **To inform decision-making regarding prioritization of wells for plugging.** Agencies may wish to include the methane emissions category as one of the factors used to prioritize and select wells for plugging. For example, plugging wells that 'may be high' would help to optimize methane emissions reductions; whereas plugging wells with no detectable emissions during screening is less likely to generate substantial emissions reductions. This protocol provides a fast, economical way to generate well class information.
3. **To improve efficiency and reduce expenses during methane quantification for reporting purposes; wells with no detected methane would not require quantification.** The main protocol (Part IV) recommends using this screening technique as a time and money saving first step in methane quantification. If methane emissions *are not detected* using the screening protocol, then the rate would be recorded as < 1 gram/ hour and no further effort need be expended. If emissions *are* detected, then the qualified measurement specialist would quantify them as described in the main protocol.

Preparing for On-site Methane Detection and Classification

Field Personnel Requirement

At least one individual on each field search team should be qualified to conduct methane leak detection, ideally with 20+ hours of training and experience with the specific equipment type and/or methods.

Detection Equipment/Instrumentation

1. Plan to use one of the sensitive 'non detect/detect' (binary) types of measurement instrumentation to classify methane or total hydrocarbon emissions. Sensitive binary instrumentation should have a detection limit of 1 gram/hour or lower. Some high sensitivity binary instrumentation includes:
    a. Gas Rover
    b. Sniffer
    c. Trace Gas Analyzer (TGA)
    d. Ring Down Laser Absorption Spectrometer (RDLAS)
2. Some less sensitive binary measurement instrumentations may be useful for rapidly visualizing the plume location at the well site (e.g., OGI camera). These can also be used to categorize a well as 'detected' if gas emissions appear as higher than background levels near a well opening or near legacy infrastructure such as a well head. Because these instruments are less sensitive, if methane levels do not appear to be different than background levels, a high sensitivity instrument (see 1 above for examples) should then be used to verify that the well is a non-detect. This process can be an effective approach for finding and locating leaks that may be missed using other instruments, particularly when legacy infrastructure is present.
    a. Optical Gas Imaging (OGI) Camera, plume detection.
    b. Tunable-Diode Laser Absorption Spectroscopy (TDLAS).

Pre-approval of planned measurement instrumentation and methodological approaches

The specific measurement equipment and methods proposed by the contractor or qualified measurement specialist should be submitted for approval to the relevant agency in advance of the field campaign. These additional criteria should also be met:

1. The weather/environmental conditions under which the method is effective should be documented.
2. Minimum detection limits for plume emissions measurements resulting in a 'non detect' classification should be no more than 1 gram/hour.
3. Leak detection EPA Method 21 - Determination of Volatile Organic Compound Leaks is preferred when well heads or other infrastructure is present.
4. In the case where there are multiple leaks from a single well (i.e., a well head is present and is leaking from more than one valve), the number of leaks will be noted, and maximum emissions concentration recorded (ppm).

5. A QA/QC process is recommended where the agency or contractor makes a second set of measurements at ~5% of wells to verify effectiveness of the selected methodology.

On-Site Methane Detection and Classification

What to measure and observe

Using the pre-approved measurement equipment and methodologies, described in 'Preparing for On-site Methane Detection and Classification' above, determine the emissions class for the well:

1. Classify emissions as 'Not Detected' if they do not exceed background levels using a sensitive binary measurement instrument (examples: gas rover, sniffer, trace gas analyzer). Emissions rates for wells assigned to the 'Not Detected' class are assumed to be 1 gram/hour or lower, as this is the defined detection limit of 'sensitive' binary measurement equipment. Background levels are ppm readings taken upwind and away from the well head vicinity.
2. Classify emissions as 'Detected' if they exceed background levels using a binary technology (sensitive or other). In addition:
    a. Note the place(s) where the leak is occurring
    b. Record the highest concentration observed (ppm) or use a data logger to record ppm.
3. Classify emissions as 'Detected + May be high' if the answer is affirmative to any of these questions:
    a. Do you smell gas (VOCs, H_2S)? If a gas smell is detected at any time, leave the location at once and do not further investigate. Such sites warrant high levels of caution and should only be approached with adequate PPE and other protective procedures in place. See safety precautions in primary documents. Olfactory fatigue can make odor detection by smell ineffective and this can be dangerous in locations with high concentrations of H_2S, especially if safety precautions are not in place.
    b. Can you hear gas leaving the well?
    c. Is there detectable venting of gas causing movement of the air, nearby vegetation, or bubbling in nearby surface waters?
    d. Are methane concentrations above 1000 ppm anywhere in the well vicinity?
4. <u>Optional</u>: if emissions appear to be high, consider revisiting with a different technique/equipment to quantify emissions and emission rate.

What to record

Using the database interface tool, record the following information for each well:

- Date and time of the measurement(s).
- Latitude and longitude (decimal degrees, 5-7 decimal places, WGS84) of the well.
- API number (if found), or another unique identifier associated with the well.
- The well class (not detected, detected, or detected + may be high).
- The type of measurement equipment and methodology utilized.

- The type of measurement made (methane or total hydrocarbon).

If the well has been classified as ‘detected’ or ‘detected + may be high’ then also record:

- The highest concentration of methane or total hydrocarbons observed (in ppm) or provide the data logger files.
- The place(s) where the well was leaking.
- Whether a gas smell was detected.
- Whether gas venting was audible.
- Whether gas venting was observed or felt as movement of the air or movement of nearby vegetation.
- Whether gas venting could be observed on nearby surface waters, e.g., as bubbling.
- Whether methane concentrations were $\geq$ 1000 ppm anywhere in the well vicinity.

PART IV. MAIN PROTOCOL: QUANTIFYING METHANE EMISSIONS RATES

Synopsis: Information Provided by this Protocol

This protocol is designed to provide quantitative estimates of methane emissions rates that meet Federal Program data quality objectives and can be aggregated to meet reporting requirements of the BIL Title VI, Section 40601(f)(2)(B) for methane emissions reduced by plugging and support the calculation of nation-wide inventory measures and emissions factors Section 40601(f)(2)(A).

Synopsis: Intended Applications of this Protocol

This protocol is intended for

- **Obtaining pre- and post- plugging methane emissions rate estimates** at orphaned wells where BIL funds will be used for permanent plugging and restoration.
- **Estimating methane emissions rates for well assessments**. Quantified methane emission rates will be one factor used by Federal Agencies to prioritize which orphaned wells should be plugged or remediated.

Preparing for On-site Methane Emissions Rate Quantification

Pre-approval of planned measurement instrumentation and methodological approaches. The specific methodological approach(es) and measurement equipment to be used by the qualified measurement technician should be submitted for approval to the relevant agency in advance, with attention to documenting how the technician will collect the data and meet the data quality objectives described below.

Methods and Data Quality Objectives (DQOs):

Qualified measurement specialist. This protocol is designed for a qualified measurement specialist trained in applying methane detection and quantification technologies in the field, and able to meet or exceed the data quality and completion objectives. At least one trained emissions measurement specialist (contractor or agency) will be needed to quantify methane prior to plugging and remediating wells. A qualified measurement specialist should be proficient at using gas measurement instrumentation that will be employed at the target wells, and able to make measurements that meet the data quality objectives for the measurement data. The specialist should be able to recognize and avoid safety hazards at an orphaned well and be otherwise prepared for working safely in remote conditions. Ideally the qualified measurement specialist will have 20+ hours of training and experience with the specific equipment type and/or methods.

Operating conditions. Measurements should be made within the certified operating conditions of the measurement equipment employed. The different methods and technology selected must be appropriate for the landscape, conditions, and accessibility of the site (e.g., mountains, rural areas, under foliage, roadless or not).

Minimum Detection Limits. The measurement equipment and/or methods used will provide a minimum detection limit for plume emissions measurements of 1 gram/hour or lower.

Precision. The measurement equipment employed must have a documented precision throughout the quantification range of 30% or better. If gas is leaking into and through the soil and quantification of soil leaks is attempted, the measurement equipment employed must have a documented precision of 50% or better.

Accuracy. The measurement equipment employed must have a documented accuracy throughout the quantification range of 30% or better.

Supply documentation that the measurement is traceable. Traceability is demonstrated by a documentation trail that shows that the measurement method used was suitable for the target metric (i.e., methane emission rate), the equipment used to make the measurement was properly calibrated, and that an appropriate measurement protocol was followed.

Well known benchmarks are typically NIST or ISO standards or reference materials. Other acceptable methods include:

- Standard Operating Procedures (SOP) derived from peer-reviewed papers,
- Example data from equipment showing the SOP results in measurements matching calibrated leaks within stated uncertainty needs, and
- The manufacturer calibration certificate of the methane gas sensor certifying it is stable over the period of the measurement campaign.

Other QA/QC data. Ideally, agencies will randomly select a subset of wells, for blind QA/QC checks. This mean that a different measurement specialist(s) would measure the same site and that the results would be compared. The QA/QC results will be scrutinized after the first season of methane measurements for potential fine tuning in a future version of this document.

On-site Methane Emissions Rate Quantification

What to measure and observe

Units of measurement. The measurement should be recorded in the database as grams per hour regardless of the method or technology used.

Reporting non-detects. Emissions rates under 1 gram/hour can be reported as 'no detectable emissions'. A sensitive (detection limit of 1 gram/hour) binary methane detection method may be used to determine if the well has no detectable emissions. See Part III, the Optional

Screening Protocol, for details. If emissions are not detected, then the emissions rate can be reported as < 1 gram/hour and no further quantification is needed. If methane is detected, then proceed to quantify the methane emissions rate.

Preferred protocol when infrastructure is present. If there is a well head or other infrastructure present at the orphaned well, EPA Method 21 - Determination of Volatile Organic Compound Leaks is preferred. If a well head is present, assess if the wellhead is connected to production equipment or to a gathering line. If so, the gathering line could be allowing gas to leak away from the wellbore into the soil – determine if quantification of methane release via soil is desirable or possible. The measurement methods selected need to be able to capture leaks from the specific target equipment (e.g., well head *vs*. production tank). Infrastructure includes piping, valves, fittings, well heads, and other physical components of an orphaned well that might be present at the site.

Recording multiple leaks. In the case where there are multiple leaks from a single well (e.g., a well head is leaking from more than one valve), record the rate at each leak site using a unique identifier in the field entry form, if possible, before summing emissions. The total sum of emissions from a well should be clearly identified in the database as a summed total rather than an individual or averaged measurement.

Selecting measurement equipment and methods. References regarding current equipment, technology, and methods used for quantification of leaking methane (flow rate + concentration) are provided in the final section of these guidelines and include high volume samplers, static and dynamic chambers, and combinations of various techniques. Due to the rapidly changing nature of technology and methods for measuring methane leaking from orphaned wells, this protocol intentionally allows for novel approaches so long as they meet the requirements outlined herein.

Data Collection. Data and information must meet the requirements for the relevant agency database.

QA/QC:

Demonstrating precision. Duplicate measurements will be made at ~5% of wells (randomly selected) to assess precision. These can be made on the same day as the initial measurement or on different days.

Demonstrating accuracy. The instrument should be calibrated against a reference gas. Use an emissions measurement method that has had its accuracy demonstrated against a controlled release of a known quantity of methane, e.g., a calibrated gas cylinder that releases a known emissions rate.

What to record

Record the following:

1. The date and time of the measurement(s).
2. Location of the well. Using mapping datum WGS84, record latitude and longitude in decimal degrees (5-7 decimal places).
3. The administrative unit (e.g., national forest, park, or refuge, BLM public land, etc.) on which the well is located or, if private land, the owner.
4. The name or number used by the agency to identify the well. Record any markings, if present, that may indicate:
    a. Prior owners
    b. Well serial number/information such as API or US Well ID.
5. The condition of the well by taking digital photos from 4 directions and looking down from above.
6. Using on-site equipment or a credible weather report, record:
    a. Air temperature
    b. Most recent precipitation date and amount (inches). [Methane measurements should not be collected during precipitation events.]
    c. Wind direction
    d. Wind speed
    e. Barometric pressure
7. For wells that have no detectable emissions (< 1 g/hour) as determined using a binary method, record:
    a. the emissions rate as < 1 g/hour
    b. The measurement equipment and method used (must have a minimum detection limit of 1 g/hour or less).
8. For quantitative methods: record the total methane emitted from the well over time. Units should be in grams/hour of methane or total hydrocarbons. (Note: field forms will include unique identifier and leak rate for each leak, but this does not necessarily need to be carried forward to the database entry form.)
9. Number of leaks if multiple leaks are present from a single well due to the presence of legacy infrastructure and/or soil emissions.
10. Note any uncertainty in the measurement, e.g., by making multiple measurements at the site, including concerns related to site conditions.
11. Equipment and technique used.
12. Equipment calibration data.
13. Comments by measurement specialist.

Field Report: Provide the relevant agency with a field report folder with

1. Photos (or upload them into the database).
2. Narrative description of the measurement methods used and supporting information.
3. Documentation of each method’s performance demonstrated with equipment used in the field.
4. Documentation of calibrations and maintenance of equipment.
5. Documentation of training and experience of measurement specialists (for example, 20+ hours of training including field experience with the specific equipment and methods).

6. Results of QA/QC replicate analysis of emissions measurements.

Audits: Agencies should implement an internal control review process or audit program to ensure best practices are used by measurement specialists/contractors during the performance period. After one year, a follow-up is recommended to resurvey a subset of wells that have been plugged (5% is suggested; randomly selected from wells classified as anything other than non-detect) to verify that plugging successfully eliminated leaks.

PART V. REFERENCES

These references include references cited and references that describe currently available best practices and protocols. As such, they are tied to these guidelines and are intended to supplement the Part III and IV protocols with specific operational descriptions. The references should be reviewed in detail prior to selecting technology or methods. Measurement specialists can provide novel solutions so long as they meet the expressed requirements and needs documented in this protocol.

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