February 10, 2022

Measurement of Methane Emissions: Abandoned Wells & Mines

In this memo we provide a brief overview of current technology available to detect and measure methane emissions from abandoned oil and gas wells and coal mines. We also offer recommendations on deploying these technologies based on recent research and conversations with service providers and experts.[1]

Key Takeaways

- To date, there is insufficient data to accurately estimate methane emissions from abandoned wells and mines. However, limited studies indicate that most wells emit little to no methane, and those measured as high emitters release less than 3 metric tons of methane (MT CH4) per year. Empirical measurement remains the most accurate way to quantify emissions. With currently available technology, we recommend collecting methane measurements using ground-based techniques (see #1).

- R&D investment should focus on innovating well-plugging techniques and materials and lowering the methane detection threshold of aerial survey instruments (see #2-3). The cost of plugging individual wells remains relatively expensive per ton of methane contained, pointing to the need for innovation to lower this cost (see #4).

Recommendations

1. Currently, ground-based techniques are more accurate than aerial surveys when measuring methane emissions from abandoned mines and wells. We recommend using ground-based techniques when taking measurements at wells directly prior to plugging, or during evaluations to assess the overall environmental hazards of a well.
    - Detection thresholds for most current aerial and satellite surveys fail to pick up emissions from a single abandoned well, which range from only 0.10 $MTCH_4$/yr (Lebel 2020) to 0.19 $MTCH_4$/yr (Kang 2016). The *Technology Summary* section below provides specific detection limits.
    - Many states do not include methane as a hazard when ranking abandoned wells for plugging, so measurements are not routinely taken during initial well evaluations. Data on methane emissions and program impact can be vastly improved by ensuring methane measurements occur during an initial evaluation of the well, or as plugging commences.[2]
    - Vehicle-mounted methane detection systems should be considered for detecting emissions from wells located near roadways and emissions from abandoned coal mine infrastructure, which often have available access roads.

2. R&D investments should target a) developing new well plugging techniques and materials that are more inexpensive and less carbon intensive and b) lowering the methane detection threshold of aerial survey instruments and improving precision for low-emissions sources.
    - In the U.S., most abandoned wells are still plugged using methods developed in the 1970s, and the types of materials used for plugging have not changed significantly over the last 100 years. Most plugs use cement, a carbon-intensive material, which must be transported to a well site, mixed and pumped on site in a fossil-fuel-intensive process. Additionally, research should investigate whether simply capping wells may be a faster, less expensive solution for wells not deemed environmental or human health risks.

[1] We have no affiliation to any of the technologies or providers cited.

[2] A more detailed summary of state methods and regulations has also been provided.

  - Lowering the detection threshold and improving the precision of aerial methane sensors may make it possible to measure emissions more efficiently over large areas from clusters of abandoned wells, unknown abandoned wells, and from abandoned mines.

3. To improve state inventories of abandoned wells, states should locate unknown wells using magnetometer surveys using aircraft or unmanned aerial vehicles (UAVs).
   - UAV-mounted magnetometers detect buried metal well casings and are more effective at locating abandoned wells than either aerial methane surveys or walking visual surveys. For example, the DOE's National Energy Technology Laboratory has used UAVs fitted with magnetometers to find previously unknown abandoned oil and gas wells in Pennsylvania.

4. For development and prioritization of further methane mitigation programs, consider using frameworks such as the social cost of methane to evaluate the impact per dollar of mitigation actions.
   - For example, under a conservative scenario where $2.3 billion dollars of the $4.7 billion appropriated are spent directly on well plugging, with current materials and technologies, about 115,000 abandoned wells can be plugged. Estimating that abandoned wells, on average, emit 0.2 MT CH_4 per year, about 23,000 MT CH_4 or 640,000 $MTCO_2e$ can be mitigated. [3] As a reference, the 2021 Global Methane Assessment values the social cost of methane at $4,400 per ton, or about $800 per well. Currently, the median cost of plugging a well in the U.S. is $20,000, which increases to $76,000 with surface reclamation, further demonstrating the benefit of lowering the cost of well plugging.

Recommendations to Incentivize States to Prioritize Methane

- We recommend that states which update hazard rankings or plugging protocols to include methane measurement should be further incentivized in the follow-on Performance Grants offered under the Infrastructure Investment and Jobs Act (IIJA).

- We recommend that federal funds be used to support R&D activities for states that support or develop research sites for methane measurement, well characterization, or technology innovation.
  - Few state agencies responsible for well monitoring and plugging have access to ground-based measurement technologies, which can cost tens of thousands of dollars and require training to properly use. Funding from the IIJA should support states to specifically improve this capacity.

Technology Summary Overview

Methane emissions can be detected and measured both on the ground and through aerial surveys. On the ground, portable gas chromatographs, handheld measurement devices, and handheld cameras can be used to detect methane and collect measurements at a point source. Vehicle-mounted sensors can be used to survey a landscape to detect new leaks or to quantify emissions to a low degree of precision. Unmanned Aerial Vehicles (UAVs), manned aircraft, and satellites can all be used to locate new high-volume leaks and to quantify emissions from super-emitting sources (e.g., landfills and natural gas compressor stations).

[3] Using CH4 GWP100 = 28.

Measurement Capabilities of Current Technologies

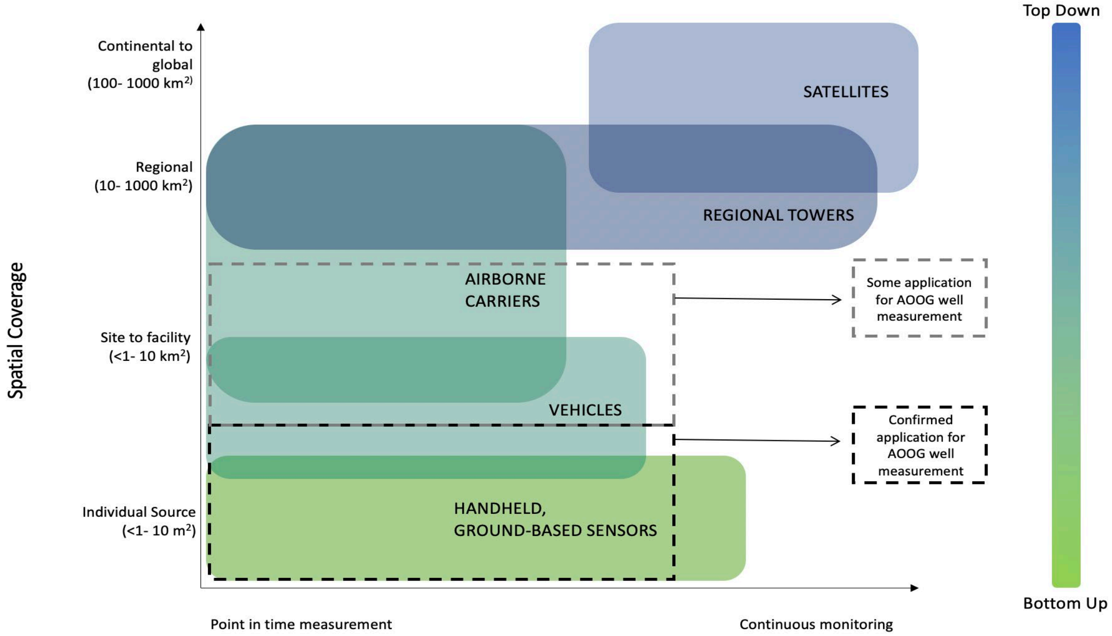

Figure adopted from National Academies of Sciences, Engineering, and Medicine. 2018. Improving Characterization of Anthropogenic Methane Emissions in the United States.

While aerial methane survey technology has vastly improved in recent years, methane detection thresholds of satellites and manned aircraft remain too high to identify emissions from abandoned wells and some abandoned coal mines. UAV-mounted sensors are more likely to detect methane from abandoned wells, but ground approaches are still necessary for precise quantification. Additionally, while a workforce could be quickly trained to collect ground measurements and record data, data from aerial surveys are difficult to interpret without specialized knowledge and the use of sensor-specific proprietary software.

Only a handful of private companies in North America provide aerial methane measurement and data processing services, which may limit aerial measurement efforts. Federal capabilities for aerial surveys, perhaps nested within the National Agriculture Imagery Program, could help expand the number and type of options available.

Methane Measurement Overview

Methane concentration and flux data can be collected using the following sensors:

- **Passive sensors** detect and quantify methane using thermal or hyperspectral imaging. Passive sensors rely on environmental conditions (temperature or sunlight) to conduct a measurement, so measurements can be compromised by cloud cover, nighttime, shadows, various angles and intensities of sunlight, foliage on trees, and certain background temperature ranges or albedos. This leads to some unreliability in measurements, especially for aerial or satellite survey equipment.
- **Active sensors** detect and quantify methane using laser spectrometry. Methane absorbs a specific range of light frequencies. In LiDAR systems, the concentration of methane is determined by transmitting a laser pulse into a gas plume and comparing the returning light to a pulse that was not absorbed. Because active sensors do not rely on environmental conditions to conduct measurements, they are more accurate and precise, generate more comparable results, and have a lower detection threshold. However, active sensors are typically more expensive.
- **Thermocatalytic or thermal conductivity sensors** must combust methane to quantify it. These sensors are limited to handheld equipment used on the ground, which comes directly into contact with leaking methane.

"Boots-on-the-Ground" Methane Measurements (Table 1)

Measuring on the ground at wells is the most commonly used method of leading emissions researchers (such as Dr. Mary Kang and Dr. Amy Townsend-Small) and plugging operators who measure methane emissions (such as Curtis Shuck, Well Done Foundation). Vehicle surveys can be more efficient where measurement targets are located near roadways. They are best suited for detecting leaks across a landscape rather than measuring them, though we have encountered situations where vehicle-mounted sensors were used to gauge the magnitude of emissions from abandoned coal mines. The technologies used for these measurements are detailed below (Table 1).

Cost and Labor Requirements for "Boots on the Ground" Measurements

System price points vary, and costs listed here represent orders of magnitude estimates.

- High precision and accuracy instruments used by researchers to measure very small gas fluxes may range from $30,000-150,000, and often involve custom builds.
- Standard instruments used by the oil and gas industry, which may be able to detect but not quantify emissions from the smallest leaks, can range from $10,000 (handheld measurement devices) into the $100,000s (hyperspectral cameras).
- The cheapest available methane measurement instruments are handheld combustible gas monitors. However, because these instruments are designed to alert the user when methane concentrations approach their lower explosive limit (5%, or 50,000ppm), their lower detection threshold too high for application at abandoned wells.

Labor costs for on the ground measurement can be substantial, as they require individuals to carry equipment to often hard-to-access sites. There is also a limit to the number of sites that can be reached per day. While upfront training is straightforward, on the ground techniques are not easily scalable.

Aerial Methane Measurements (Table 2)

Much of the recent innovation in methane detection has been geared toward active oil and gas operators. While promising, these tools do not have the precision necessary to measure methane from abandoned coal, oil, and gas sites, and struggle to measure emissions over foliage or mountainous terrain.

- A satellite survey (or a high-altitude aerial survey) will not differentiate methane emissions from active operations and abandoned infrastructure– rather, such surveys are best used for quantifying total abandoned or abandoned coal mine emissions over a region.
- Unmanned Aerial Vehicle (UAVs) such as drones offer higher granularity of data but cover less ground in a day than an airplane or helicopter.
- Magnetometer surveys are not included but could comprise an aerial alternative for locating unknown wellheads and improving state inventories. UAV-mounted magnetometers detect buried metal well casings and are more effective at locating abandoned wells than either aerial methane surveys or walking visual surveys. Once located with a magnetometer, wells would need to be measured for methane emissions on the ground prior to plugging..

Cost and Labor Requirements for Aerial Measurements

Per acre, manned aircraft surveys are most costly, followed by UAV surveys, while satellite surveys are the most cost effective. Furthermore, aircraft surveys provide point-in-time emissions insights while satellites can complement those efforts and provide continuous site monitoring.

Although the mobilization and upfront costs of aerial systems are often higher than those for ground-based measurement, over the long-term, aerial surveys are the most cost-effective method of measurement. Current aerial technologies primarily provide services to active oil and gas operators. The programs enabled by the IIJA offer opportunities for the development of a similar customer base for measurement of abandoned and orphaned infrastructure and a focus on lower-detection thresholds.

Table 1: "Boots on the Ground" Methane Measurement Technologies

	Portable Gas Chromatograph	**Handheld Measurement Devices** (incl. flame ionization detectors and high-volume dilution samplers)	**Handheld Cameras** (incl. hyperspectral and remote methane leak detectors)	**Vehicle-Based Detectors**
Purpose	- Quantification	- Detection - Quantification	- Detection - Visualization - Quantification (partial)	- Detection - Quantification (order of magnitude)
Use case	Research-grade measurements at and around a wellhead (before and after plugging).	Standard measurements at and around a wellhead (before and after plugging). Requires a standard protocol for comparable results.	Standard measurements at and around a wellhead (before and after plugging). Visualization of a methane plume. Requires a standard protocol for comparable results.	Locating unknown wells across a target landscape or detecting leaks among known wells. Detecting leaks and gauging magnitude of methane emissions at abandoned coal mines.
Examples of Known Providers[4]	- Los Gatos Research Ultraportable Greenhouse Gas Analyzer - Picarro Gas Concentration Analyzer Series	- Bacharach Hi Flow Sampler - Hetek Hi Flow Sampler - Hetek DP-IR - Bascom-Turner Gas Rover II - ABB MicroGuard - Aeris Technologies MIRA LDS Handheld	- Teledyne FLIR GF320 - Teledyne FLIR GF77 - Telops HyperCam - Sensia Mileva 33 - Sensia Caroline Y - Hetek RMLD-IS	- ABB MobileGuard - Portable Methane Leak Observatory (Canada, not yet commercial) - Aeris Technologies MIRA LDS - Boreal GasFinderV-3B - Physical Sciences Inc. Remote Methane Leak Detector
Cost	~$30,000-150,000	$10,000-$20,000	~$100,000	Various, starting at $3,000
Measurement technology	Gas chromatography (active)	Thermocatalytic and thermal conductivity sensors; infrared imaging (passive)	Infrared imaging (passive); remote methane leak detection (active)	Laser-based technologies (active): laser is either outward-facing (like LiDAR) or contained (gases are sucked through a gas analyzer)

[4] The providers listed in Table 1 and 2 aim to provide a representative sample of services and providers but should not be seen as a comprehensive list.

	Portable Gas Chromatograph	**Handheld Measurement Devices** (incl. flame ionization detectors and high-volume dilution samplers)	**Handheld Cameras** (incl. hyperspectral and remote methane leak detectors)	**Vehicle-Based Detectors**
Advantages	- Anyone can be trained to use this equipment and interpret data - Currently the most precise and accurate instrument for methane measurement (used by researchers) - Can check methane flux from surrounding soils via chamber measurements (if gas from reservoir is leaking around the wellhead)	- Anyone can be trained to use this equipment and interpret data - May check for methane flux from surrounding soils via bar holing - Already used by oil and gas workers and researchers - Lightweight and designed to be portable	- Handheld or mounted onto UAV for navigating difficult terrain - Methane leaks are visible to the naked eye, making it possible to quickly determine their precise origin - Lightweight and designed to be portable	- May be used to locate new abandoned wells or methane seeps - Identifies wells that are both accessible (near roads) and leaking methane - Enables rapid surveys over a large area - May be used to assess emissions from shafts and gob wells at abandoned coal mines - A portable gas chromatograph can be easily reconfigured into a vehicle-based sensor (no special sensor required)
Limitations	- Cannot be used to locate new abandoned wells or methane seeps - Requires a chamber setup with a known volume and an airtight connection to the wellhead. Wellhead conditions vary and there is no standard setup - Current setups may be difficult to maneuver in the field - The instrument is easy to damage, and repairs are expensive and require	- Cannot be used to locate new abandoned wells or methane seeps - High flow sampler can measure flows of 0.05 scfm and up - Labor intensive to deploy	- Unlikely to be useful for locating new abandoned wells or methane seeps - Process to calculate flux from visuals is involved - Hyperspectral cameras can have difficulties detecting low concentrations of methane - Labor intensive to deploy	- Cannot be used to collect precise measurements from individual wells - Technologies developed and used to detect gas leaks in cities and pipelines; applicability for locating abandoned wells is assumed rather than demonstrated

	Portable Gas Chromatograph	**Handheld Measurement Devices** (incl. flame ionization detectors and high-volume dilution samplers)	**Handheld Cameras** (incl. hyperspectral and remote methane leak detectors)	**Vehicle-Based Detectors**
	manufacturer to repair - Labor intensive to deploy			
Photo				

Table 2: Aerial Methane Measurement Technologies

	Unmanned Aerial Vehicle (UAV)	**Manned Aircraft**	**Satellites**
Use Case	Identifying point sources of high methane emission with precision.	Identifying clusters of high methane emission with precision.	National/regional GHG inventory.
Lower Detection Threshold	Sensor manufacturers report concentration sensitivities down to 0.01 ppm, and fluxes down to 0.1kg CH4/hr ~0.9 MT CH4/year; flow down to 1scf/hr	**For passive sensing:** 10 kg CH4/hr → 87.6 MT CH4/yr **For LiDAR:** 0.5 kg CH4/hr → 4.4 MT CH4/yr (a more conservative estimate is 3 kg CH4/hr ~ *26 MT CH4/yr*)	100 kg CH4/hr → 876 MT CH4/yr
Example Technology Providers *Best suited for active oil and gas emissions monitoring **Sensor only; must be mounted onto aircraft	- ABB HoverGuard* - Telops HyperCam Airborne Mini** - Baker Hughes LUMEN Sky - Aeris Technologies	- Ball Aerospace Methane Monitor (sensor developed but not commercialized) - Telops HyperCam Airborne Mini** - Sierra-Olympic Ventus OGI**	N/A
Example Service Providers *Best suited for active oil and gas emissions monitoring	- Flogistix AirMethane - SeekOps - Aerometrix	- Bridger Photonics - GHGSat - Lasen, Inc.*	- GHGSat - Orbital Sidekick* - MethaneSAT*

	Unmanned Aerial Vehicle (UAV)	Manned Aircraft	Satellites
	- Lasen, Inc.*	- Kairos Aerospace*	- Carbon Mapper*
Cost	Variable as cost is dependent on whether a flyover is contracted as a service and includes data processing, or if equipment is directly purchased to perform flights	**For passive sensing:** \$10,000-15,000 per day, with daily coverage up to 400-500km^2 (99,000-124,000 acres) - excluding mobilization costs **For LiDAR:** \$400,000 for 50,000 acres - including mobilization costs	Service is not yet commercially available at scale. At least two non-profits (MethaneSAT and Carbon Mapper) are expected to launch methane-monitoring satellites in 2023 which will make data from 'hot spots' publicly available
Measurement area	400 acres/day	**For passive sensing:** 64,000-100,000 acres/day **For LiDAR:** 3,125 acres/day (LiDAR)	- Swath 12km wide, pixels 25m x 25m (low precision) - Swath 200km wide, pixels 130m x 400m (high precision) - Monitoring every 1-4 days
Measurement Technology	Passive (infrared) or active (laser) sensing	Passive (infrared) or active (laser) sensing	Passive sensing only (no space lasers yet)
Advantages	- Lower detection threshold than other aerial methane survey options - may be used to identify very high-emitting wells - Sensors can be bought separately and integrated with any commercial drone	- Covers more ground than UAV	- Continuous and inexpensive long-term monitoring
Limitations	- Slower (covers less ground) than other aerial methods - Requires targeted approach and a sense of where wells are located - Data interpretation is difficult and often requires proprietary software and trained individuals to interpret - Cost	- Unlikely to tag well-specific emissions - Data interpretation is difficult and often requires proprietary software and trained individuals to interpret - High costs for each study - Mobilization and logistical costs are high as aircraft must first be transported to the measurement site	- Satellites detect and measure methane emissions at a regional scale or from large emitters, but cannot attribute emissions to a single point source of an abandoned well or mine