# Drones and UAVs for Methane Emissions Detection, Monitoring, and Regulatory Compliance

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**Abstract**
New developments in drones and unmanned aerial systems (UAS) can enable operators to comply with new methane emissions regulations from the Environmental Protection Agency which took effect in August 2016, and those from the Bureau of Land Management which took effect in November 2016. The new regulations contain specific monitoring and reporting requirements for different types of oil and gas operations, from upstream production facilities to midstream processing and transportation. This paper reviews the requirements, and examines current solutions, including various types of drones and sensors. In addition, the paper discusses how to go about planning drone flights, given the different types of installations to be monitored and the legal restrictions in place.

**Keywords**
Drones, unmanned aerial vehicles (UAV), fugitive methane, gas detection, infrared sensors, airborne surveys, thermal mapping, photogrammetry

**New Regulations for Methane Emissions Monitoring in Oil and Gas Operations**

Developing an economic and efficient plan to monitor and detect fugitive methane emissions in all aspects of oil and gas production, processing, and midstream operations is more important than ever. New technologies are being implemented, including new sensors and the use of drones, both fixed-wing and multi-rotor.

New regulations from the Environmental Protection Agency (EPA) came into effect on August 2, 2016. They require monitoring of oil and gas operations to detect fugitive emissions of methane. Published on June 3, 2016, in the *Federal Register,* the new regulations pertain to oil and gas operations in both upstream (drilling, completions) and midstream (processing and transportation). The new EPA regulations were published in the *Federal Register* https://www.federalregister.gov/documents/2016/06/03/2016-11971/oil-and-natural-gas-sector-emission-standards-for-new-reconstructed-and-modified-sources

The new requirements require initial and ongoing reviews, detection, and monitoring to assure that there are no leaks or emissions. While many of the operations are monitored, many such as pipelines are in inaccessible locations, and they traverse canyons, mountains, rivers, all of which are vulnerable to environmental conditions that accelerate corrosion.

In addition, the Department of the Interior's Bureau of Land Management announced on November 15, 2016, the Methane and Waste Prevention Rule, calls for reducing harmful methane emissions and eliminating flaring, venting, and leaks (BLM, 2016). The stated goal is to cut methane emissions from the oil and gas sector from 40-45 percent from 2012 levels by 2025 (BLM, 2016).

Drones are highly effective for conducting checks for methane emissions, as well as visual evidence of corrosion. They are also ideal for conducting period checks, especially for remote operations after natural disasters. Conducting a survey after initial installation and then each quarter is required by the regulation. While it might be a good idea to include sensors that are constantly monitoring the wells, there may be a problem with connectivity and consistent appropriate power supply.

The new regulations specifically identify emission sources (Federal Register, 2016, p. 35826):

- Wet seal centrifugal compressors (except those located at well sites)
- Reciprocating compressors (except those located at well sites)

- Pneumatic controllers at natural gas processing plants
- Pneumatic pumps at natural gas processing plants and well sites

- Well completions

- Fugitive emissions from
    - Well sites
    - Compressor stations

- Equipment leaks at natural gas processing plants

Industries affected by the new regulations (Federal Register, 2016, p. 35828)

| | |
|---|---|
| NAICS code 211111: | Crude petroleum and natural gas extraction |
| NAICS code 211112: | Natural gas liquid extraction |
| NAICS code 221210: | Natural gas distribution |
| NAICS code 486110: | Pipeline distribution of crude oil |
| NAICS code 486210: | Pipeline transportation of natural gas |

**Identifying Operations Requiring Monitoring**

As mentioned earlier, the operations requiring periodic monitoring are in the oil and gas industry, both in upstream and midstream operations. The first step involves developing a list of operations, along with locations and a "heat map" that prioritizes them according to the likelihood of accidents or emissions.

**Producing Gas Wells and Midstream Operations:**
Must accurately locate them using GPS and find production statistics in order to be able to predict and profile the production (natural gas, oil, condensate, other gases).

**Wellhead:** Each well needs to be identified, along with the production equipment to help predict where leaks can occur. While methane emissions are a part of the regulations, it is important to also identify other fugitive gas emissions, such as nitrogen, H2S, CO2, and more. Obviously identifying an H2S leak via drone would be a bit late in the game because it would mean that volumes significant enough to be detected are already in the atmosphere, which is very dangerous. Nevertheless, the ability to also detect H2S would be a good value-add.

**Gas gathering systems:** Location is critical, plus the type and purpose of the gas gathering system needs to be identified and defined so that the kind of equipment is detailed, as well as the types of processes as well as most likely types of leaks. While methane

**Compressors / Gas conditioning units:** Can be a part of the gas gathering system, or can be near the wellhead. These need to be identified: location first, and then the type of equipment, processes, and most likely locations for gas leaks should be pinpointed.

**Pipelines:** Where the pipelines tie in is most critical. Nevertheless, it is useful to survey the entire pipeline because corrosion and metal fatigue can also result in methane emissions.

Drones can be used in conjunction with pipeline security, particularly where there are high incidences of pipeline vandalism and oil theft. The drones can be deployed when a pressure monitor detects a significant change in the pressure in the pipeline, which suggests theft or vandalism. Drones equipped with cameras (including night-vision sensors) can be used to identify the thieves or vandals (Idachaba, 2016).

**Multipurpose.** The drones used to monitor methane emissions can be multipurpose. The sensors used to detect methane emissions can also be used to detect plant stress, which could be helpful for agricultural purposes, and also in the case of a below-ground seep of gas or saltwater (Sanders, etal, 2016).

## Developing a Monitoring Plan

To be in compliance with the new regulations, pipeline and oil and gas operators must develop a monitoring plan. It is permissible to use digital picture reporting:

"The EPA is finalizing digital picture reporting as an alternative for well completions and manufacturer installed control devices as proposed. Specifically, the final rule allows digital picture reporting as an alternative for well completions and manufacturer installed control devices" (Federal Register, 2016, p. 35870). The "latitude and longitude output of the GPS unit can be clearly read in the digital photograph" (Federal Register, 2016, 35870).

Critical information regarding monitoring gas gathering systems and gas compressors (Granholm, 2016):

1. Must develop a plan for monitoring fugitive emissions and detecting leaks. The plan must
   * use optical gas imaging (OGI)
   * OGI uses infrared detectors
   * Images are "real time"
   * May use a portable volatile organic components (VOC) monitoring instrument

2. New or modified compressors
   * must conduct an initial survey
   * must take place within 60 days of startup (or one year after the publication of the Methane Rule)
   * monitoring must take place on a quarterly basis

3. Repair leaks
   * must complete within 30 days of detection
   * exception if it requires an entire shutdown. You may repair leaks during the next scheduled shutdown (or within 2 years)

4. May use alternative monitoring technology
   * must submit report to the EPA
   * must explain how the alternative technology can detect leaks
   * must demonstrate the new technology is as effective as optical gas imaging or portable monitoring instruments that detect volatile organic components

**Using Drones for Periodic Monitoring and Episodic Emissions Detection in the Oil Industry**

Drones of all sizes and capacities, ranging from small multirotor drones to large fixed-wing long-range unmanned aerial systems (UAS) can be used effectively to both monitor and detect emissions.

Successful deployment of drones and unmanned aerial systems for oil field monitoring depends on the correct combination of drones, sensors, and flight path / plan.

**Developing the Flight Path**

The plan for collecting information via drone should be mapped out quite carefully.

Here are a few questions to ask:

Are all the operations you are monitoring covered by the same lease?
Same operator?
What is the spacing? Have the gas wells been unitized?

Depending on the legal situation, you may need to confine each flight path to a single lease, a single operator, or a single landowner (depending on the contracts with the surface owner).

**For individual installations (individual wellheads, gas gathering systems, etc.):** Much depends on the spacing and the orientation of the gas gathering systems and compressors, etc. It may be that, due to restrictions on leases, battery time, and geography, each lease may involve a separate survey. You will need to carefully examine the structures on the surface: structures, roads, etc. in order to avoid problems.

**Pipelines:** If you are conducting a survey of a pipeline, it is very important to have an accurate map so that your flight path goes above the pipeline. Depending on the pipeline -- if it is a main one, or simply an intermediary pipeline that ties the lease to a cross-country pipeline, you may be able to accomplish longer surveys and cover several miles of pipeline with each individual survey.

**Matching Sensors and Drones with the Realities of the Operations**

There are a number of factors to consider when determining the best drone and sensor combination for your operations.

**Multirotor systems** capable of vertical takeoff and landing are ideal for many leases where there are problems of difficult topography, concentration of equipment requiring complicated passes, limited space, and restrictions due to the location (buildings, roads, infrastructure).

Multirotor drones may have limited air time, and may have weight restrictions, making the sensor payload decision more complicated.

**Fixed wing systems** can travel longer distances while staying within the line of sight. They are ideal for surveying linear features (pipelines, roads, etc.) and also for identifying anomalies in a large, relatively homogeneous space (areas of flooding, feral hogs in fields, etc.). However, they may not be viable in locations where there are topographical hazards (mountains, etc.), interfering structures (buildings), legal restrictions (surface owner prohibitions), power lines, or other issues. It may be more difficult to obtain permissions unless it's within an official right of way.

Fixed wing systems tend to be more robust and capable of carrying a much heavier payload. That allows a wider array of sensors to be included.

**Sensors and Data Collectors**

**Cameras:** A wide array of digital image collectors are available. Cameras can be programmed to take individual still shots or to record a video. The resolution can vary dramatically.

**Infrared systems:** Spectral detection of heat, resulting in heat maps, with useful information that can be used to identify hot spots, heat loss, geothermal zones, as well as small-source heat generators (animals, people, warm engines).

**Laser systems:** Laser sensors can be used to identify where gases or other elements are causing the light sources to bend, and the refraction can be measured to determine they types of elements / gases that correspond to specific angles or spectral signatures.

**Data collectors for drone-mounted methane sensor systems**
Detecting methane emissions can be used by a number of different types of sensors.

Detecting spills of fluids rather than fugitive gas emissions is not constrained by wind speed or direction. However, there can be other challenges, such as absorption into the ground and vegetation.

Drones can be configured with different types of sensors, which include

* Synthetic aperture radar (SAR)
* Multi-spectral imaging
* Laser-based methane gas detectors
* Forward-looking infrared (FLIR) cameras
* High-resolution visual cameras (including video)
* Thermal imaging via a wide array of infrared cameras

For use in drones, the sensors must be both light and stable (Pipeline Leak Detection Handbook, p. 166). Other issues must be considered as well, such as terrain, extent of the leak or spill, and the legal parameters.

**WASC.** A variety of sensors have been used in conjunction with drones in order to measure air quality and also to detect the presence of certain types of gases. Chang etal (2016) used a multicopter-carried whole air sampling component (WASC) in order to provide real-time information. The air samples entered the WASC and flowed into a canister across sensors.

The sampling positions and flight paths were entered on a laptop which contained a flight control algorithm (Chang etal, 2016). The total weight of the remote-controlled WASC was 1515g. The cost of the multicopter, plus the WASC was approximately $12,000.

While the experiment was successful, certain limitations were described:
* weather conditions (especially wind) affect flight stability and the accuracy of the sampling
* the multicopter was effective, largely due to vertical take-offs and landings, agility with maneuvering, and the ability to hover
* because the multirotor craft and the sensors can be reused, the initial investment cost can be amortized over a number of projects

**OPLS.** In another project, NASA's Jet Propulsion Laboratory's sensor: Open Path Laser Spectrometer (OPLS)
* can detect methane in parts per billion by volume
* can fit on multi-rotor drone (Vertical takeoff and landing)
* tested with propeller drone February 2016

The Pipeline Research Council International funded research to develop a hand-held, open path laser spectrometer (OPLS) capable of measuring natural gas based on tunable laser spectroscopy at 3.3. um lasers. Key capabilities:
* measures methane in 10 parts per billion sensitivity
* weighs less than 150 grams
* time response of greater than 1.2 hertz
* OPLS can identify methane sources 10 - 200 meters away
* OPLS can integrate with
  sniffer measurements
  infrastructure GIS

The goal is to develop an aerial robotic methane sniffer.
Phase 2 of the project will include deploying in small unmanned aerial system (PRCI, 2016).

**Off-Axis ICOS.** Greenhouse gases were detected and measured using a new infrared Off-Axis Integrated Cavity Output Spectroscopy (Off-Axis ICOS) by Berman etal (2012). The battery and sensors were relatively heavy and so a fixed wing Unmanned Aerial Vehicle (UAV) was used. The sensors measured CO2, H2O and CH4 in flights in Crow's Landing, California, and in Svalbard, Norway (Berman etal 2012). The sensors detected anomalies that were well out of the range of noise (Berman etal, 2012, p. 124).

**Hyper-Cam.** Some researchers have preferred using infrared for methane emission detection. Watremez etal (2016) used hyper-spectral cameras. They developed algorithms for data obtained using the Hyper-Cam, "a commercial hyperspectral imager producing high-resolution radiometrically calibrated data in real-time" (Watremez, etal, 2016, p. 3). The gas signature of methane is observed when there is adequate thermal contrast (difference between the emitted gas and the background thermal background scene). After a number of tests and revisions, the key problems in reliability had to do with accurately accounting for wind speed and direction. In this case, the infrared sensors were fixed and located near a gas processing plant. They could conceivably be used with drones.

**Boreal Open-Path Laser Gas Monitor**. Hugenholtz and Barchyn (2016) demonstrated in a "proof of concept" study that a fixed-wing drone (2.3 m wingspan) with 90-minute flight endurance carrying a Boreal Laser open-path laser gas monitor with an integrated transmitter/receiver unit and a passive reflector. The results demonstrated that a methane plume could be detected and mapped, at least in conditions of little or negligible wind.

**Integrated Sensor and Data Logger.** Many companies such as Pergam manufacture a methane detector for UAVs that connects with a companion Data Logger (Pergam Technical Services, 2015). There are advantages and disadvantage in using a preprogrammed, prepackaged data logger / sensor combination. Using the preprogrammed / prepackaged combination can save time, but the main issue is that they are not flexible and may not provide the information needed. However, creating a custom solution can be time-consuming and expensive.

Another company, Aerialtronics.com, has developed a UAV system dedicated to VOC and gas detection drones.

**FLIR Thermal Imaging Cameras**
FLIR has developed a high-resolution thermal imaging camera that can be mounted on both fixed wing and multi-rotor drones. The camera, which is less than $2,000 integrates with an application that works with both iOS and Android cell phone systems. Connecting with GPS as well as digital picture imaging can help develop a survey with multiple uses. Lower-cost FLIR cameras used with cell phones can be obtained for as low as $200. They are not intended for high-resolution data collection, but are effective when mounted in a fixed location where they are completely stationary, and can be used for comparing the information gathered in flight, with that which was gathered by a stationary sensor.

**Workswell Thermal Imaging Systems**
Workswell has a wide array of thermal imaging systems that include cameras, software for the batch administration of thermograms, and the a CorePlayer for the analysis, editing, and exporting to a wide array of formats. The Workswell WIRIS allows real-time control by a standard remote control radio transmitter on the drone.

**Conclusions and Recommendations**

While it may be tempting to purchase a drone and then determine how to use it for emissions detection and monitoring, it is more effective to begin with the operations that need to be monitored, and then develop a solution that is ideal for the specific need. While the first deployment may be expensive, due to equipment and development costs, the repeated utilization of the drone emissions monitoring solution will result in the ability to amortize the initial investment over time, resulting in a more cost effective ultimate outcome.

It is important to continually review case studies to learn from the successes and failures of others, particularly in the application of a solution in the real world, where variables such as wind speed, wind direction, meteorological conditions, along with the physical realities of the equipment (as opposed to the capabilities under optimal conditions).

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