Community Air Monitoring of Oil and Gas Pollution:

A SURVEY OF ISSUES AND TECHNOLOGIES

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Introduction

While the United States has a long history of oil and gas development, the recent rise in activity has been rapid and steep. Between 2000 and 2014, more than 173,000 new natural gas wells went into production, while the average rate of oil production grew nearly 50%.[1] As of 2014, there were more than 1.1 million active oil and gas wells nationwide.[2]

Much of the most recent development can be attributed to the shale boom, which has intensified drilling in many places and introduced it in others. Increasingly, operations have expanded to include, alongside well pads, the processing and transportation facilities needed to move the gas and oil to market. Despite a recent dip in operations, industry and state governments continue to plan for increased development in the coming years.

Expanded activity has also increased the range of potential environmental and health impacts. In turn, a strong focus on pollution of the water we drink has increasingly been complemented by questions about risks to the air that we breathe.

This shift in part stems from growing attention to the climate impacts of natural gas—which is pure methane, a greenhouse gas over 80 times more potent than carbon dioxide. A recent study estimated that during 2002-2014, US methane emissions increased more than 30%, likely in large part due to the shale gas and oil boom.[3] The US Environmental Protection Agency (EPA) projects that methane emissions from the oil and gas industry could increase 25% in the next decade. [4]

Both conventional and unconventional oil and gas operations involve heavy industrial processes, which by definition release a variety of health-harming pollutants. Pennsylvania's air emissions inventory shows that between 2011 and 2013, volumes of total volatile organic compounds (VOCs) emitted by unconventional gas wells increased 70% and benzene 66%. [5] In the Uinta Basin of Utah, VOCs emitted by the oil and gas industry increased nearly 80% between 2006 and 2012 and now account for almost all VOC pollution in the region.[6] A study in the Eagle Ford Shale of Texas projected that by 2018, VOC emissions could be 200-450% higher than in 2012, depending on the level of development. [7]

Communities living on the frontlines of oil and gas development have long been the first to notice the impacts of worsening air quality and to sound the alarm for the general public, decisionmakers, and the media. Recent studies have found that health symptoms are more frequent and risk levels higher among people living closer to wells and facilities than among those further away. [8]

In addition, the health symptoms reported by residents living in proximity to oil and gas wells and facilities are often quite similar. Studies in several states have identified similar patterns in potential exposures and resulting symptoms, in particular respiratory problems, eye and throat irritation, headaches, nausea, and stress.[9]

Given these trends, it is not surprising that oil and gas field residents nationwide are asking basic questions: "What's in my air?" and "Why is it making me sick?" Yet both regulators who oversee the oil and gas industry and policymakers determining its course have only been able to give partial, ambiguous answers.

Residents, organizations, and researchers have increasingly taken on the search for more solid answers. This survey paper discusses many of the different air monitoring methods currently being used in community-based projects that are designed to increase understanding of oil and gas pollution. It also considers the reasons why—in the face of increasing emissions and reports of health problems—more monitoring is necessary to understand the air quality impacts from the oil and gas industry and, ultimately, to ensure that impacted residents get the information they need and deserve to protect their health.

I. Missing Pieces of the Air Puzzle

The effects of many of the chemicals and pollutants associated with oil and gas development are scientifically well-established.[10] Less clear is how to "connect the dots" from Point A, an emissions source; to Point B, exposure by a person; and to Point C, resulting health problems. While research to investigate such connections is rapidly emerging,[11] establishing direct connections remains challenging. Two key reasons are limitations in air quality data for wells, equipment, and facilities; and inadequate standards against which to evaluate the impacts of oil and gas pollution on health.

Limited Air Quality Data

State and federal environmental and regulatory agencies do not regularly monitor the air directly around well sites and facilities, although some testing may be conducted when severe problems occur or in limited studies.[12] In addition, there is a lack of localized "baseline" air quality data that show conditions prior to oil and gas activities—making it harder to pinpoint the new sources and increased levels of pollution once development becomes widespread.

Air quality monitors do exist across the United States, primarily those required by the EPA and operated by states.[13] These are mainly located in populated areas to track pollution from traffic, power plants, and other ongoing sources across broader regions. However, this regional approach generally doesn't capture pollution in the more rural areas where oil and gas wells and infrastructure have been more prevalent and may be the only significant local source of emissions.

In addition, the national air quality system tracks six "criteria pollutants" that have associated National Ambient Air Quality Standards (NAAQS) and are regulated under the US Clean Air Act: carbon monoxide, nitrogen oxide, sulfur dioxide, ozone, particle pollution, and lead.[14] While very important, this system doesn't include other pollutants associated with oil and gas operations, in particular methane and a host of volatile organic compounds (VOCs).

Although federal limits exist for some Hazardous Air Pollutants (HAPs), or air toxics, released by industrial activities (e.g., hydrogen sulfide and formaldehyde), oil and gas wells and associated equipment are not included as area sources of air pollution in the federal law governing HAPs.[15] EPA does monitor emission trends for several HAPs through National Air Toxics Trends Stations (NATTS) set up across the United States, but few of these are in areas with oil and gas development.[16]

Even where emission inventories are undertaken, they may only include reporting for some parts of the oil and gas industry. For example, Pennsylvania's inventory (in place since 2011) is limited to unconventional wells and exempts reporting of emissions from certain activities (e.g., well drilling and completion).[17]

According to a 2013 report by the Inspector General of the EPA on the National Emissions Inventory (NEI), 35 states had submitted oil and gas production emissions data for point sources (i.e., specific wells and facilities), but only 9 had submitted data for nonpoint sources (i.e., the various equipment used throughout the development process).[18] The report concluded that, "Because so few states submitted data for this sector, we believe the NEI likely underestimates oil and gas emissions. This hampers EPA's ability to accurately assess risks and air quality impacts from oil and gas production activities." [19]

When oil and gas operators apply for permits for compressor stations, processing plants, and other facilities, they base statements about their air emissions on estimated volumes. It is only after facilities are operating that actual emissions may become clear (if states require operators to report them), potentially resulting in underreported pollution. In a 2013 study, the RAND Corporation found that when compressor stations in Pennsylvania operate below capacity, they fall at the lower end of their estimated emissions—but whenever they don't, actual emissions are higher than volumes declared in permit applications. [20]

Further, state and EPA emission inventories collect data in terms of the total volume (in tons) emitted over the course of several months or a year. Emission levels are not tracked for different times of the day or week, and are not reported in terms of the concentrations of a pollutant. Yet such information is necessary to understand the timing and intensity of pollution and the exposures that can cause health problems.

Nor do statewide data reflect localized impacts on air quality and health experienced by many residents. A 2013 RAND Corporation study showed that in Pennsylvania counties where gas and oil operations are concentrated, NOx [nitrogen oxide] emissions were 20-40 times higher than levels equivalent to "major" emission sources (a permitting classification applied to large facilities but not well sites).[21]

Pollution levels vary during different phases of development (e.g., drilling, fracturing, production, or processing) and can greatly increase during events such as venting and flaring at well sites, liquids unloading during production, and blowdowns that release pressure at compressor stations. Industry recognizes the fluctuating nature of pollution from events such as blowdowns, which can last for several hours but are most intense during the first 30-60 minutes. [22]

Emerging environmental health research confirms that episodic emission events can cause health impacts immediately or in as little as 1-2 hours, largely because toxicity is determined by the concentration of the chemical and intensity of exposure.[23] As a result, longer-term, average emissions levels alone cannot provide a full picture of exposure.

Inadequate Health Standards

People living near gas wells and facilities day in and day out, as well as workers at job sites, are often subjected to multiple toxic substances simultaneously and on a chronic, long-term basis. Yet this experience is not reflected in the health standards used by agencies to determine the impacts of chemicals and the relative safety or risk of exposure to them. Regulators and health agencies have developed these standards through testing of individual chemicals and "safety" is based on one-time (generally 8-hour) exposures. [24]

Most of these risk assessments of exposure to a particular substance are based on healthy adults, so impacts on more vulnerable populations such as children, the elderly, and those with pre-existing health conditions, can be underestimated. In addition, risk assessments for many chemicals use a high dose as the starting point for calculating levels at which negative effects can be observed—potentially minimizing the exposure risks of low doses of multiple chemicals.[25] A 2012 study, for example, showed that endocrine (hormone system) disrupting chemicals can have different but still harmful effects at lower doses than at higher ones, concluding that fundamental changes in chemical testing and safety protocols are needed to protect human health.[26]

A 2015 paper on endocrine disrupters concluded that in order to determine exposure risks, it's necessary to understand what happens when multiple chemicals interact and mix.[27] As summarized by the Agency for Toxic Substances and Disease Registry, "most toxicological testing is performed on single chemicals, but human exposure is rarely limited to single chemicals…A particular issue is whether a mixture of components, each of which is present at less than guidance concentrations, may be hazardous due to additivity, interactions, or both." [28]

Finally, health-based standards do not even exist for most of the 187 toxic or hazardous air pollutants that are known or suspected to cause cancer and other serious health effects.[29] A study on air toxics by the University of California-Berkeley School of Public Health concluded that, "Lack of consistent monitoring data…makes it difficult to assess the extent of low-level, chronic, ambient exposures to HAPs that could affect human health." [30]

2. The Evolving Field of Air Monitoring

The three trends discussed above combine to undermine a true assessment of air pollution and related health impacts in oil and gas development areas: a lack of consistent, real-time air monitoring near operations; significant gaps in air emissions information on both the state and federal levels; and limited health-based standards with which to judge the risks experienced by residents.

In the absence of action by state and federal regulatory agencies to fill these wide knowledge and data gaps, impacted communities, researchers, advocates, and health professionals are increasingly motivated to conduct air monitoring projects of their own.

Such projects are based on an inherently different approach from that found in mainstream air quality monitoring. Instead of a focus on tracking an established set of pollutants on a statewide or regional scale, they seek to identify the pollutants emitted on a community (or even household) level. When possible, associations are made between air data and health symptoms reported by residents living in proximity to specific pollution sources.

Moreover, these projects aim to put the findings directly into the hands of affected residents and to force a response by regulators, policymakers, and industry that would help reduce air pollution from oil and gas operations. These two motivations have been behind Earthworks' air testing and health survey projects in several states.[31] The dual goals of community support and regulatory response are also the basis for Earthworks' documentation of air emissions at wells and facilities using a state-of-the-art infrared camera.[32]

The following sections are based in large part on Earthworks' experiences and observations conducting air testing in the field, as well as research on the approaches taken (and challenges faced) in other community-based projects.

Project Considerations

Community-based monitoring projects have been conducted under varying circumstances in different oil and gas development areas. However, a set of factors has emerged that need to be considered when designing a project.

Primary goal. The technology selected and testing schedule will be largely determined by the goal at the outset of a project. For example, whether one wants to take a broad look at which pollutants are present in the air; identify concentrations close to a specific site, piece of equipment, or phase of activity; or attempt to detect specific pollutants associated with odors or health symptoms reported by nearby residents.

Affordability. Budgets often determine the extent and type of monitoring conducted by non-profit organizations, community groups, residents, and academic institutions. The cost of purchasing and operating monitors may influence the selection of one technology over another, the extent to which they are deployed in a particular geographic area, and the frequency of testing.

Ease of use. Although some training is necessary to use any piece of equipment, the selection of a particular monitoring technology should consider whether it can be understood, deployed, and collected by people without advanced technical knowledge or skills.

Timing. It is more likely that localized air pollution will be detected when the potential sources are emitting (e.g., during production or when compressor stations are running). But operators do not publicize their schedules and some events occur suddenly (e.g., an accidental release or filling of a waste impoundment). Nearby residents and site visits can help identify when operations are underway, for example based on odors, noise, and traffic. Infrared imaging can also indicate whether emissions are occurring at a given time.

Response time. Some of the largest releases of emissions can occur during specific events (such as flaring or venting). Capturing these events requires technologies that can be available onsite or stored nearby for rapid deployment in the field, as well as people who are available to conduct a test on short notice. In contrast, monitoring of normal operations can be planned ahead of time and conducted on a set schedule by project participants or coordinators who have to travel to testing sites.

Frequency and scope. Conditions at locations slated for monitoring can vary considerably and are often unpredictable. As a result, it may be necessary to conduct tests frequently enough to increase the likelihood of detecting pollutants and identifying trends. It may also be necessary to deploy multiple tests in a wider area (e.g., on different sides of a well pad or processing plant) in order to capture emissions from different locations at different times.

Chemical parameters. A growing body of science on air pollution from oil and gas operations,[33] together with knowledge of the pollutants emitted by any industrial facility, makes it possible to test for contaminants that are likely to be present. As discussed below, some technologies test for only one or a few parameters, while others allow for analysis of a broad set of gases and VOCs.

Type of analysis. For technologies that rely on laboratory analysis, the organization or community selects which substances to test for. Project goals will likely guide this decision, although budget may also be a factor (the more parameters to be analyzed, the more it costs). It's important that the laboratory has equipment sensitive enough to detect chemicals at low concentrations, in order to minimize the reporting of chemicals as "non-detect" even if they were present in the air. The lab's Minimum Detection Level (MDL) and Method Reporting Limit (MRL) should be lower than health-based or air quality standards that exist for the selected pollutants. [34]

Field considerations

Air monitoring can be complex and challenging. Several factors need to be considered in order to maximize the chances of detecting pollutants and collecting usable data. Some of these factors (e.g., weather) are relevant for all projects, while others depend on the chosen technology and project protocols.

Source. Oil and gas development involves multiple well sites, pieces of equipment, and facilities in the same vicinity. These "area sources" release emissions that blend together; there are also many sources of "fugitive emissions," which result from cracks, leaks, and faulty seals in pipes or equipment.[35] Given this, it may not be possible to pinpoint the exact source of emissions being tested.

Access. In some places, it is possible to get fairly close to well pads, equipment, and facilities without trespassing. In other situations, sites may be located along gated driveways or in such a way that they are virtually invisible (e.g., below a steep hill or behind trees). Permit documents, mapping programs, satellite imagery, and local contacts can help identify the location and accessibility of specific sources of pollution. In turn, this information can help determine good locations for testing.

Distance. The distance between where air samples are taken and the targeted source of air emissions depends on what one is trying to figure out. If the primary goal is to show associations between particular sites and reported health symptoms, it's better to test as close to the potential pollution source and affected households as possible. But if the goal is to determine broader pollution trends generated by multiple sources, longer distances may be preferable. In addition, concerns about potential harassment by industry personnel and being able to work without being seen by facility operators may also dictate where one tests.

Weather and wind. According to EPA, how long a pollutant can be detected in the air "depends on its reactivity with other substances and its tendency to deposit on a surface; these factors are governed by the pollutant form (i.e., chemical compound) and weather conditions including temperature, sunlight, precipitation, and wind speed." [36] It's therefore important to consider the weather when deciding where and when to test for pollutants.

For example, particulate matter can move more slowly when it's cloudy and calm, while VOCs tend to disperse quickly in high winds. The emissions source may also influence how pollution moves; for example, a plume from a stack will go higher up in the air than leaks from pipes. It's important to check wind direction and position monitoring or sampling equipment so that potential pollutants are more likely to blow toward than away from it.

Topography. One of the most variable factors in oil and gas development areas is the landscape itself. As discussed above, wind largely determines how pollutants are transported through the air; in turn, wind can be affected by topography. Generally speaking, wind moves air directly across wide, open plains or fields, changes speed and direction around mountains and hills, sinks low into valleys, and can be blocked by trees and vegetation. A full assessment of topographical effects requires modeling that may be beyond the scope of many community-based projects.[37] However, it's still beneficial to consider landscape features when selecting testing locations.

Test duration. Some monitoring equipment can only be used for pre-determined periods of time, while other technologies are designed for continuous monitoring. How one tests can depend on a combination of the project goal and circumstances. For example, if attempting to detect pollution during a short, intense venting or flaring event, "grab" samples of several minutes might be sufficient. If trying to track pollution that's always present around operations, monitoring for several hours or days might be necessary to capture intermittent emissions. If equipment needs to be left in the field, it will be necessary to have secure testing locations.

Interference. Although much oil and gas development is occurring in rural or suburban areas with little industrial activity, other air pollution sources (such as roads) are likely to be present. Because these other sources can make it harder to draw connections between testing results and a specific pollution source, taking a "baseline" air test before a well site or facility is operational can provide data that can be compared with later air tests. However, even when this isn't an option, certain pollutants only come from industrial (i.e., not household or agricultural) activities so it can still be possible to establish associations with oil and gas sources.

3. Monitoring Technologies

Given that there are hundreds of known pollutants and countless circumstances in which they could be measured, it makes sense that many different monitoring technologies exist. As interest in new sources of pollution grows, additional equipment is also being created or adapted.

The broad application of sophisticated, highly technical monitors could certainly help identify local and regional air impacts in oil and gas development areas, and resulting data could help communities better understand their potential exposures and health risks. However, this section does not address the various types of complex (and expensive) equipment used by operators, regulators, and some academic institutions.[38]

Instead, the following discussion focuses on the primary technologies currently being used and tested by, or created for, community-based projects. They represent an effort to use equipment capable of measuring pollutants associated with oil and gas development, while also being affordable, obtainable, and feasible in a range of field settings.

All of the methods discussed here have advantages and disadvantages. Currently, there is no one "silver bullet" monitoring method or approach that has completely characterized oil and gas field pollution. Communities face particular conditions and have different reasons for conducting monitoring projects, while researchers may seek to detect specific pollutants. According to the Southwest Pennsylvania Environmental Health Project, air pollution data reported in studies vary precisely because of the inherent challenges of monitoring and because "no single sampling method can accurately capture all of the essential data." [39]

Active Sampling

Active sampling relies on a valve, pump, or other mechanism to pull air into a sampling vessel, which is then analyzed for the presence and concentration of specific pollutants. Active sampling represents a "moment in time," i.e., it captures only whatever pollutants are present when the sample is taken. Numerous pollutants can be detected; the community or organization decides which ones are included in the analysis conducted by a laboratory.

Summa Canisters

A summa canister is a stainless steel vessel that has been specially coated on the inside and outside to prevent contamination. Summas are used to collect "whole air" samples of VOCs and permanent gases (e.g., nitrogen or methane). They work through vacuum; that is, once opened, the canister pulls in air and the pressure inside falls as the sample is collected. Summas are available to rent from laboratories that are certified by state or federal environmental agencies. The labs pre-calibrate the canisters (via an accompanying flow controller valve) depending on the length of time that the client wants to test for: from a one-minute "grab sample" up to a maximum of 24 hours. The analysis of tests conducted for longer periods will present data in terms of time-averaged concentrations; by leveling out peaks, this can understate pollution levels present at certain times. Summas have the advantage of being supplied and analyzed by laboratories, while also being relatively easy to use based on written instructions or simple training. Regulatory agencies often use Summas and accept them as a reliable testing method.

Since Summas have to be ordered and shipped from labs, their use requires planning and can make it difficult to provide a "rapid response" to sudden, short pollution events. Most gases can remain stable in canisters for several days, so Summas offer flexibility in when to test and ship them back to the lab. However, this is not the case for sulfur compounds (such as mercaptans or hydrogen sulfide), which have very short holding times and must be analyzed by a lab within 24 hours of when they were collected.

Organizations, community groups, and researchers have used Summas in oil and gas areas. Many labs provide them, but Earthworks and partner organizations have relied on ALS in Simi Valley, CA (www.alsglobal.com). In 2015, rental of a single canister with laboratory analysis for methane and the suite of VOCs included in the EPA's "TO-15" method cost about $300.

Tedlar bags

Bags made of tedlar, a heavy, durable plastic, are widely used in chemical and gas sampling. They can collect "whole air" samples of permanent gases (e.g., nitrogen and methane), sulfur compounds (e.g., mercaptans and hydrogen sulfide), and VOCs. Tedlar bags must be contained in some sort of container and combined with a pump. A vacuum is created inside the sampler, which forces the bag to expand and draw in an air sample.

Projects in oil and gas areas have relied on "buckets" created and supplied by Global Community Monitor or "lung" samplers that can be rented from laboratories. Once a sample is taken, the bag is removed from the container, sealed, and sent to a certified laboratory for analysis.

Tedlar bags can be used only for "grab" samples lasting from a few seconds to several minutes. They are most effective when wells or facilities are known to be emitting (which might be clear from odors and noise). On the other hand, if pollutants are detected, they are likely to be in higher concentrations because they are barely averaged out, in contrast to longer tests. Bag samplers have the advantage of being relatively easy to use based on written instructions or simple training. If acquired from an organization, residents or local groups can keep them on hand for extended periods of time—making it possible to respond quickly to sudden events (e.g., a blowdown or well fire). However, gases in Tedlar bags don't remain stable for long periods, so samples must get back to a lab quickly (within 24-72 hours depending on the holding time of the compound being analyzed).

Organizations, community groups, and researchers have used Tedlar Bags in oil and gas areas. Global Community Monitor provides assistance to communities in organizing "bucket brigades" using Tedlar bag and other sampling methods (http://www.gcmonitor.org/communities/start-a-bucket-brigade. Lung samplers and instructions are available from ALS labs in Simi Valley, CA, www.alsglobal.com; in 2015 a sampler with analysis for sulfur compounds cost $75, plus $15 per one-liter tedlar bag.

Public Lab formaldehyde kit

The Public Laboratory for Open Technology and Science (Public Lab) is a global community of people developing and applying open-source tools for environmental investigation. Public Lab creates inexpensive and accessible Do-It-Yourself tools that can be used easily in the field, including in oil and gas development areas.

Public Lab's formaldehyde kit is a combination of plastic sampling tubes to detect the pollutant and a basic pump to create airflow. Public Lab is currently working with a community group in Pennsylvania to conduct a formaldehyde monitoring pilot project using both the Do-It-Yourself kit and a portable sensor-based gas detector.[40] Once collected, the samples can be analyzed onsite.

Passive Sampling

Passive, or diffusive, sampling relies on the diffusion, or flow and mixing, of air. This promotes the collection of pollutants onto the surface of a porous material, which can then be analyzed for the presence and concentration of specific pollutants. Depending on the technology used, passive samplers can test air for several minutes, hours, or days.

Passive sampling represents a "moment in time," i.e., it captures only whatever pollution is present when the sample is taken. Analysis is conducted in a laboratory, and the chemical concentration is averaged out for the sampling period. Passive samplers are generally calibrated to detect single pollutants.

Badges

Badges are a commercially available technology often used for surveys of pollutants in a specific area. They are small and can be deployed easily and discreetly by hanging them on a person or a stationary object, such as a tree or fence. However, because they are directly exposed to the air, weather can affect the functioning of badges.

In oil and gas development areas, badges have been used to test for compounds that can't be captured with other affordable methods. For example, formaldehyde badges have been used in combination with chemical testing for VOCs and methane. Global Community Monitor deployed over 40 formaldehyde badges in five states as part of a broader study of pollution from wells and facilities.[41] The Group Against Smog and Pollution (GASP) in Pennsylvania used formaldehyde badges in combination with Summa canisters as part of a program to provide air data to residents experiencing odors and health symptoms.[42]

Many companies sell badges for different compounds. Formaldehyde and BTEX chemical (benzene, toluene, ethylbenzene, and xylene) badges are available for $39 each from ACS badge; http://acsbadge.com/residential.shtml. ALS labs in Simi Valley, CA provides UMEX formaldehyde badges for $25 each, plus $85 for analysis; www.alsglobal.com. SKC, Inc. sells UMEX formaldehyde samplers in packs of 10 for $159; https://www.skcinc.com. Assay Technology sells TraceAir badges in packs of 5 for about $200-300 including analysis of 1-4 chemicals or $500 for analysis of a suite of 25 chemicals; http://www.assaytech.com.

Tube sampling

This type of diffusive sampler has a tube made of porous polypropylene plastic and material inside it capable of adsorbing a specific pollutant. For example, tubes for testing H2S are coated with zinc acetate, tubes for VOCs are coated with carbon, and tubes for testing formaldehyde are coated with silica.[43]

Sorbent tubes are manufactured for use in conjunction with an air flow pump. The Radiello tube is contained in a cartridge and can be used as a passive sampler for outdoor air monitoring to detect VOCs and BTEX, H2S, ozone, and several other pollutants. They have been used in community-based air testing projects in oil and gas development areas in Wyoming and Texas.

Various companies can provide Radiello tubes. For example, Sigma Aldrich sells packs of 20 cartridges for H2S or VOC/BTEX for about $300, plus $50 per sample for analysis; http://www.sigmaaldrich.com. They are also available from ALS labs in Simi Valley, CA for $30 each, plus $50 per sample for analysis; www.alsglobal.com.

OSU samplers

Oregon State University (OSU) and the University of Cincinnati are currently deploying two types of passive samplers to measure polycyclic aromatic hydrocarbons (PAHs) in an Ohio community with intensive shale gas development.[44] Both were designed and calibrated by researchers at the Environmental and Molecular Toxicology department at OSU.

One of the samplers consists of strips of low-density polyethylene (LDPE) plastic with a metal housing and is capable of detecting over 60 PAHs. They were deployed at homes near gas wells and facilities for 3-4 weeks. Residents then collected the samples and shipped them to a lab for analysis.[45]

According to EPA, to evaluate the impact of air pollution on health, it can be useful for people to "wear devices that measure air quality as they go about their daily routines. In the future, people may monitor their own exposure to air pollution to help make medical decisions." [46] OSU's second sampler, a silicone-based wristband, reflects this personal exposure research approach.[47] The wristband is currently part of a monitoring kit that also includes a mobile phone to track location and a spirometer to test lung function. [48]

Public Lab detectors

The Public Laboratory for Open Technology and Science (Public Lab) is a global community of people developing and applying open-source tools for environmental investigation. The project creates inexpensive and accessible Do-It-Yourself tools that can be used easily in the field. Public Lab is developing two technologies that test for toxic pollutants with severe health impacts, but which have not been widely measured in oil and gas development areas.

One uses photographic paper to visualize the neurotoxic gas hydrogen sulfide (H2S). The photographic paper contains silver halide, which tarnishes when exposed to H2S and changes color depending on the level of H2S exposure. To date, Public Lab has field-tested the canisters in New Mexico, Wyoming and Texas.[49] The kit to test for H2S is designed to be made by anyone with access to a darkroom. Currently used to identify hotspots for corrosive gases and support further research, a team at Northeastern University is investigating ways to base this testing method on quantitative analysis. For more information, see Public Lab's website (https://publiclab.org) or contact team leader Sara Wylie at s.wylie@neu.edu.

In addition, Public Lab is currently developing a low-cost passive sampler for particulate matter that is built with a glass disk housing, mesh, and an aluminum Scanning Electron Microscopy (SEM) pin stub. It is currently being field tested near fracturing sand mines in Wisconsin.[50]

Sensors

Air quality sensors use some sort of housing to hold sensors capable of detecting different pollutants. Based on metal-oxides or similar materials, they work by detecting changes in resistance or light when a gas or particle reacts with the sensor surface. According to EPA, "The new generation of low-cost, highly portable air quality sensors is providing an exciting opportunity for people to use this technology for a wide range of applications beyond traditional regulatory or regulatory-equivalent monitoring." [51]

The sensors described here are currently being used or field-tested in oil and gas development areas by researchers and non-profit organizations, sometimes in collaboration with academic institutions that calibrate the sensors and analyze the data. A key challenge with this type of technology is the development of sensors that are both sensitive enough to detect fluctuating concentrations of VOCs and other pollutants, yet remain affordable.

Sensor-based monitors are designed to run continuously and detect variable concentrations of pollutants over time. This makes it possible to track spikes in pollution levels, to compare the data to events that occur at particular well sites or facilities, and, in turn, potential health exposures. Data are uploaded to an online platform or mobile application.

Sensors can be simple to deploy and operate. They can be housed in such a way as to facilitate discrete fieldwork (e.g., to look like a mailbox or bird box); handheld devices are also an option. Sensors can be used singly, or set up as a network (for example, several surrounding a target facility). However, they generally require a power source and technical expertise to analyze resulting data.

When using air sensors, it's important to check whether a particular technology's function can be affected by conditions such as high humidity, rain or snow, direct sunlight, or excessive dust. It's also possible that sensors will have to be repeatedly calibrated to avoid "drift," or the loss of responsiveness over time that can result in inaccurate pollution concentration measurements. [52]

Speck monitor

The Speck monitor measures fine particulate matter (PM2.5). It was developed by the CREATE Lab at Carnegie Mellon University as an inexpensive indoor air quality monitor. In oil and gas fields, it has been used to date primarily by the Southwest Pennsylvania Environmental Health Project, which has deployed over 250 monitors at households in Pennsylvania, Ohio, West Virginia, and New York. [53]

While the Speck only detects one pollutant, changes in PM2.5 could also reflect fluctuations in VOCs, which can adhere to particles. By carrying chemicals into the lung and potentially the bloodstream, particulate matter can potentially increase the dose of a single or multiple chemicals.

Specks can record detections of PM2.5 continuously for about a month. However, if they are linked to specksensor.com via a wifi connection, Specks can upload data for an unlimited length of time. Users can choose whether to keep the data private or allow it to be viewed publicly, for example as part of a community-wide monitoring project in which residents can see and compare exposures.

Specks can be used outdoors and indoors. When using them indoors, it can be beneficial to have participants complete a home exposure assessment in order to identify household activities that are unrelated to oil and gas activities. Speck monitors cost about $200. More information is at https://www.specksensor.com/.

Dylos monitor

The Dylos Corporation has developed several models of indoor air quality monitors that can measure particulate matter ranging from 0.5 to 2.5 microns. Dylos monitors register detections continuously, but data can only be recorded for 24 hours before it has to be downloaded.

Breathe Easy Susquehanna County (BESC) in Pennsylvania is currently using Dylos monitors to detect changes in air quality near gas facilities. BESC and Reducing Outdoor Contaminants in Indoor Spaces (ROCIS) are conducting air monitoring using a combination of the Dylos (which can detect fine particles) and the Speck (which can run for a longer time).

In addition, Dylos Monitors will be used in an air and health exposure study in Lost Hills, California run by Clean Water Action, Earthworks, Kern Environmental Enforcement Network, and the California Department of Public Health. For this project, researchers with the University of Washington have adapted the Dylos to work with their own circuitry, cellular connectivity, and data management systems. They are also using a customized photo ionization detector (PID) to continuously track total VOCs in Lost Hills.

When using the Dylos indoors, it may be necessary to track household activities to identify activities that are unrelated to oil and gas activities. Dylos monitors cost about $200-300. More information is at http://www.dylosproducts.com.

The Citizen Sense Kit

This kit was designed by the Citizen Sense project based at Goldsmiths, University of London. The project works with communities to use sensors for environmental monitoring. From 2013 to 2015, Citizen Sense developed and installed a monitoring kit near homes and natural gas infrastructure (such as compressor stations) in Pennsylvania.

The kit included a Frack Box, which combines several sensors to detect nitrogen oxide, nitrogen dioxide, ozone, and VOCs and includes humidity, temperature, and wind sensors to determine the effects of those factors on air pollution levels. Data from the Frack Box was compared and collected along with PM2.5 data from a Speck monitor (see description above) and data on the BTEX chemicals from passive sampling badges.

Citizen Sense is currently investigating options for refining the kit and developing a data visualization tool and guides so that citizens can develop their own monitoring programs. More information is available at www.citizensense.net.

Clean Air Council sensor

The Clean Air Council (www.cleanair.org) is a non-profit education, advocacy, legal, and community service organization based in Pennsylvania. Active on oil and gas issues statewide, the Council is currently developing a low-cost sensor-based monitor specifically for use near compressor stations and other facilities.

The Council's monitor will use four sensors to detect particulate matter, nitrogen dioxide, methane, and total VOCs. It will also include a temperature and humidity sensor in order to assess the influence of those factors. Data on the concentrations of the different pollutants will be measured continuously for up to two weeks and uploaded to a map using a mobile phone app. Clean Air Council will field test the monitor in 2016 in collaboration with community groups.

SNAQ boxes

The University of Cambridge has developed the Sensor Network for Air Quality (SNAQ) monitor. Its sensors detect nitrogen oxide and dioxide, carbon monoxide and dioxide, sulfur dioxide, ozone, total VOCs, and particulate matter. The SNAQs have primarily been used to monitor air quality around London's Heathrow airport.[54]

Environmental health researchers with the University of California Los Angeles recently established a network of SNAQs and passive air sampling badges (discussed above) to monitor the air around a massive gas leak from the underground gas storage field in Aliso Canyon. The monitors were set to continuously record detections over a period of several days.

4. The Monitoring Horizon

Despite decades of oil and gas development in the United States, both health impacts research and air monitoring initiatives have been consistently underway only since the shale boom began in the late 2000s. As a result, community-based approaches to air monitoring currently constitute an evolving pursuit.

As with all research, community-based projects strive to use comprehensive, accurate approaches that can yield usable, credible data. To achieve this goal, it has been necessary to apply existing technologies in different situations, develop new technologies, and devise protocols to capture pollution from a range of operations.

Community-based monitoring is currently an imperfect science—but one that is vital to pursue and apply more widely. Every project yields valuable data and ideas on how to refine and adapt technologies and testing protocols to be more effective in capturing and profiling oil and gas pollution. In addition, the work is essential to respond to an ever-growing number of community needs and reports of negative health impacts.

Many areas in the United States already have compromised air quality and are currently in violation of federal air standards for certain regulated air pollutants, in particular ozone (smog). Over time, wells, equipment, pipelines, compressor stations, processing plants, and other facilities are likely to have an additive, negative effect on air quality nationwide.

Ideally, regulators that oversee the oil and gas industry would address this growing source of pollution by expanding air monitoring systems and using resulting data to establish stronger pollution controls and community protections. Technically advanced continuous monitors would be able to capture fluctuating emissions caused by both "normal operations" and intense pollution events from sources across wide areas.

However, in the absence of such progress on the governmental level—itself a result of inadequate funding and political support for research and regulatory agencies—alternative approaches will continue to try and fill the gap. EPA has acknowledged this, as evidenced by the agency's "Air Sensor Toolbox for Citizen Scientists" and the testing and evaluation of low-cost sensors and other equipment by agency scientists.[55]

For the foreseeable future, the nimble, affordable air monitoring technologies described in this survey paper—as well as new and refined ones that will continue to emerge—will drive future air monitoring in oil and gas development areas. The innovation and adaptation of technologies holds much promise, as do partnerships among local organizations with deep knowledge about conditions on the ground and academic institutions with technical and analytical capabilities.

Additional financial resources, capacity, expert involvement, and engagement of impacted communities will make more air monitoring possible in more places. With that expansion of data would come a fuller understanding of oil and gas pollution sources and patterns, and resulting effects on health and the environment. Most importantly, residents who live on the frontlines of development and are subjected to air pollution every day will have greater access to information they can use to protect themselves, demand change, and begin to breathe more easily.

5. Information and Monitoring Resources

CitizenAir is an online forum to communicate, share research and information, and develop collaborations on air quality monitoring by groups, organizations, and government: http://citizenair.net

Citizen Sense is a project that works with communities to use sensors for a variety of environmental monitoring, including related to oil and gas: http://www.citizensense.net

Clean Air Council is an education, advocacy, legal, and community service organization with information on air quality and energy issues: http://cleanair.org

Earthworks' community health research page, with links to air testing data and reports from several states: http://health.earthworksaction.org

Earthworks' Citizen Empowerment Project, including information on the role of infrared cameras in tracking air pollution and videos of oil and gas wells and facilities in eight states: https://www.earthworksaction.org/voices/detail/citizens_empowerment_project

Global Community Monitor works with communities to conduct environmental monitoring, including in oil and gas development areas: http://www.gcmonitor.org

Physicians, Scientists, and Engineers for Healthy Energy maintains a database of peer-reviewed research studies on the impacts of oil and gas development, including related to air quality and monitoring projects: https://www.zotero.org/groups/pse_study_citation_database/items

Public Lab, a Do-It-Yourself environmental science and monitoring community, with links to air pollution detection projects: https://publiclab.org

ShaleTest conducts infrared videography of emissions and air and water testing on behalf of residents and communities that are negatively impacted by oil and gas extraction: http://www.shaletest.org

Southwest Pennsylvania Environmental Health Project provides air monitoring, health information resources, and access to health professionals for residents in natural gas development areas and conducts research on air and health impacts: www.environmentalhealthproject.org

US EPA Air Sensor Toolbox for Citizen Scientists, including information on affordable technologies for air quality monitoring, data guidelines, and sampling methods: http://www.epa.gov/air-research/air-sensor-toolbox-citizen-scientists

USEPA Next Generation Air Measuring Research, including overviews of efforts to expand the types and use of monitoring technologies: http://www.epa.gov/research/airscience/air-sensor-research.htmairscience/air-sensor-research.htm

6. Endnotes

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[12] Examples of limited state efforts include:

In 2015-2016, SoCal Gas and the South Coast Air Quality Monitoring District conducted periodic air testing around a massive methane leak from the Aliso Canyon gas storage fiend in southern California. Background and results are at http://www.arb.ca.gov/research/aliso_canyon_natural_gas_leak.htm

In 2012, the Texas Commission on Environmental Quality conducted limited pollution detection in the Eagle Ford Shale in response to ongoing complaints by residents, but determined that pollution levels were too high for monitoring to be conducted safely. See *Reckless Endangerment While Fracking the Eagle Ford*, Earthworks 2013, https://www.earthworksaction.org/library/detail/reckless_endangerment_in_the_eagle_ford_shale.

In 2010-2011, the Pennsylvania Department of Environmental Protection conducted what it referred to as “limited air sampling initiatives;” see regional reports at http://www.dep.pa.gov/Business/Air/BAQ/MonitoringTopics/ToxicPollutants/Pages/default.aspx In 2012, DEP launched a one-year, continuous monitoring study, the results of which have not yet been released. http://www.ahs.dep.pa.gov/NewsRoomPublic/SearchResults.aspx?id=19520&typeid=1

[13] USEPA Air Quality System, AirData information: http://www3.epa.gov/airdata/index.html

[14] See USEPA's air monitoring page at http://www3.epa.gov/airquality/montring.html

[15] See legal petition pertaining to the US Clean Air Act filed in 2014 by Earthjustice on behalf of over 60 groups nationwide: http://earthjustice.org/sites/default/files/files/OilGasToxicWellsPetition51314.pdf

[16] See USEPA, "National Air Toxics Trends Stations." http://www3.epa.gov/ttnamti1/natts.html

[17] See Earthworks 2014. *Blackout in the Gas Patch: How Pennsylvania Residents are Kept in the Dark on Health and Enforcement*. http://blackout.earthworksaction.org.

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- "Community Health Survey Results of Pavillion, Wyoming," 2010, http://earthworksaction.org/PR_PavillionHealthSurvey.cfm
- *Natural Gas Flowback: How the Texas gas boom affects community health and safety*, 2011, http://www.earthworksaction.org/library/detail/natural_gas_flowback
- *Gas Patch Roulette: How Shale Gas Development Risks Public Health in Pennsylvania*, 2012, http://health.earthworksaction.org
- *Reckless Endangerment While Fracking the Eagle Ford*, 2013, https://www.earthworksaction.org/library/detail/reckless_endangerment_in_the_eagle_ford_shale
- *Blackout in the Gas Patch: How Pennsylvania Residents are Left in the Dark on Health and Enforcement*, 2014, http://blackout.earthworksaction.org
- *Californians at Risk: An Analysis of Health Threats from Oil and Gas Pollution in Two Communities*, 2015, https://www.earthworksaction.org/files/publications/CaliforniansAtRiskFINAL.pdf.

[32] See an overview of Earthworks' Citizens Empowerment Project and infrared videos from oil and gas areas in eight states at https://www.earthworksaction.org/voices/detail/citizens_empowerment_project.

[33] See entries on air quality in the Physician, Scientists, and Engineers for Healthy Energy's citation database of peer-reviewed studies: https://www.zotero.org/groups/pse_study_citation_database/items/collectionKey/FX6WTII3

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- Gas Chromatography-Flame Ionization Detectors (GC-FID) and remote methane detector for leak detection and repair (LDAR) activities. See for example http://heathus.com/product_category/gas/flame-ionization-fid and http://heathus.com/products/methane-leak-detector

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[54] A conference poster describing the sensors and their application is at http://www.ch.cam.ac.uk/files/posters/Jones(Rod)1.pdf.

[55] See EPA's citizen science for air monitoring reports and resources at http://www.epa.gov/air-research/air-sensor-toolbox-citizen-scientists. Note that EPA used $2500 as the basis for "low-cost sensors," which is much higher than the technologies described in this paper. We believe that the EPA cost level would be prohibitive for many non-profit organizations and community-based groups, particularly if multiple sensors are to be deployed to capture emissions from different sources and to account for fluctuating field conditions.