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Summary on Compressor Stations and Health Impacts
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Compressor station emissions

Compressor station emissions fall into two categories: construction emissions and operational emissions. Within operational emissions there are three types that warrant individual attention – blowdowns, fugitives and accidents. This document provides perspective on the aptness of the method of estimation (in tons per year) and need for further detail about the VOC and PM estimated emissions to better consider health risk.

Compressor construction and operational phases are generally projected to produce emissions below the NAAQS standards. They are presented in *tons per year*. This measure of emissions is used for NAAQS purposes which determines the air quality designation over a region and over long periods of time. The problem posed by estimating tons of contaminants emitted per year is that over the course of a year emissions will vary, often greatly. As phases of construction and operation change so will emissions content and concentrations. For a resident living near a compressor station, the concern is not simply PM2.5 emissions over the course of a year, but is PM2.5 emissions during the peak construction time when it's at its most intense.

Even during normal operations compressor stations have been shown not to emit uniformly ("blowdown" and accident events will be discussed separately).[1] The measurement *tons per year*, while common in the industry and common in the environmental field where regional air quality is at issue, is not an appropriate measure to determine individuals' health risks which increase during episodes of high exposures.

Table 4 shows the day to day and morning to evening variability in emissions at one compressor station near Hickory, Pennsylvania. It comes from a Pennsylvania Department of Environmental Protection. We present this case to show documentation of fluctuations not captured by averages.[2] Note how much relevant emissions information is lost when relying on averages, even of just three days. When extending this logic across a year, there is little doubt that there will be times of high levels of contaminants released and these high levels can increase health risks to residents. It is also notable that the EPA inhalation reference concentration (RfC) for ethylbenzene is 1 mg/m3 (equivalent to 1,000 ug/m3).[3] Some of the reported emissions exceed this standard of health safety.

Table 1. Variation in ambient air measurements of five VOCs near a compressor station reported in ug/m^3 *[4]

Chemical	May 18		May 19		May 20		3 day average
	morning	evening	morning	evening	morning	evening	
Ethyl-benzene	No detect	No detect	964	2,015	10,553	27,088	6,770
n-Butane	385	490	326	696	12,925	915	2,623
n-Hexane	No detect	536	832	11,502	33,607	No detect	7,746

*The PA DEP collected data on many more chemicals than those listed above; the authors of this paper have chosen these chemicals specifically to highlight variation in emissions.

Documented compressor emissions

It is important to know, with more specificity, what chemicals will be emitted by a compressor facility so that a targeted assessment can be made about its potential health impacts.

There is a small but growing body of literature on emissions from shale gas extraction, processing and transport activities. In its early stages of inquiry, the focus was predominantly on drill pad activity, but there are now some reports on natural gas compressor station emissions. Below are examples of chemicals that have been found at or near compressor stations during operations. These emissions reports – whether from public databases or from a private sector firm or organization – do not provide relevant background levels of the chemicals detected. Without a "control" location it is not possible to say with certainty that the chemicals found are the result of the compressor station, although these facilities are often the only industrial activity in the areas where they are found.

Emissions from two compressor stations (Stewart and Energy Corps), published by the Pennsylvania Department of Environmental Protection (DEP)[5] are:

MTBE
CO
iso-Butane
methyl mercaptan
n-Butane
n-hexane
n-octane
nitrogen dioxide
nitrous-
acidstyrene
2-methyl butane
2 methyl pentane
3 methyl pentane
ethyl benzene
benzene
ethane
propane
methanol
napthlelene

The Texas Commission on Environmental Quality (TCEQ), as part of its Barnett Shale Formation Area Monitoring Projects found the following chemicals downwind from two monitored compressor stations[6]:

- Downwind of Devon Energy Company LP's Justin compressor station the TCEQ reports propane, isobutene, n-butane, ethane, cyclohexane, benzene, n-octane, toluene, m+p-xylene, n-hexane.
- Downwind of Targa North Texas LP's Bryan Compressor Station the TCEQ reports: ethane, propane, isobutene, n-butane, cyclohexane, n-octane, toluene, isopentane, n-pentane + isoprene, benzene.[7]

Officials in DISH, TX commissioned a study of compressor station emissions in its vicinity. Wolf Eagle Consultants performed whole air emissions sampling for VOCs, HAPs as well as Tentatively Identified Compounds (TICs). Chemicals identified as *exceeding* Texas's ESLs include: [8]

benzene
dimethyl disulfide
methyl ethyl disulphide
ethyl-methylethyl disulfide
trimethyl benzene
diethyl benzene
methyl-methylethyl benzene
tettramethyl benzene
naphthalene 1,2,4-trimethyl benzene
m&p xylenes
carbonyl sulfide
carbon disulfide
methyl pyridine
dimethyl pyridine

In 2011 and 2013, Earthworks, a non-profit organization, collected air samples within 0.33 miles of two compressor stations: Springhill compressor in Fayette County and the Cumberland/Henderson compressor station in Greene County, Pennsylvania.[9] Results from samples collected include:

1,1,2-Trichloro-1,2,2-trifluoroethane,
1,2-dichlorobenzene
2-butanone
benzene
carbon tetrachloride
chloromethane
dichlorodifluoromethane
ethylbenzene
methane
methylene chloride
tetrachloroethylene
toluene
trichloroethylene
trichlorofluoromethane

Anecdotally, we know that people living near compressor stations report episodic strong odors as well as visible plumes during venting or blowdowns. Residents often report symptoms that they associate with odors such as burning eyes and throat, skin irritation, and headaches. These are simply anecdotes but they are fairly consistently reported. It should be noted that residents in southwest Pennsylvania where these anecdotes were collected, often live near drill pads and in some instances processing plants along with compressor stations.[10]

Emissions pathways

In addition to the emissions produced during the normal operations of a compressor station there are several other ways that emissions might be dispersed from the site. These include fugitive releases, blowdowns, and accidents. Trucks play a significant role in the emissions profile during construction but are not common once the facility is complete and on line.

Fugitive emissions

Fugitive emissions are uncontrolled or under-controlled releases. They occur from equipment leaks and evaporative sources. It has been suggested that fugitive emissions will increase over time as machinery begins to wear.[11]

There does not appear to be a central publically available source of information of these emissions. There are, however, many opportunities for fugitive emissions to be released from a compressor station. We were able to locate only one study on natural gas compressor station fugitive emissions. In that study, conducted in the Fort Worth, TX area, researchers evaluated compressor station emissions from eight sites, focusing in part on fugitive emissions. A total of 2,126 fugitive emission points were identified in the four month field study of 8 compressor stations: 192 of the emission points were valves; 644 were connectors (including flanges, threaded unions, tees, plugs, caps and open-ended lines where the plug or cap was missing); and 1,290 were classified as Other Equipment. The Other category consists of all remaining components such as tank thief hatches, pneumatic valve controllers, instrumentation, regulators, gauges, and vents. 1,330 emission points were detected with an IR camera (i.e. high level emissions) and 796 emission points were detected by Method 21 screening (i.e. low level emissions). Pneumatic Valve Controllers were the most frequent emission sources encountered at well pads and compressor stations.[12]

Blowdowns

The largest single emission at a compressor station is the compressor blowdown.[13] They can be scheduled or accidental. As the natural gas rushes through the blowdown valve, a gas plume extends upward of 30 to 60 meters. The most forceful rush of air occurs at the very beginning, then the flow gradually slows down. The first 30 to 60 minutes of the blowdown are the most intense, but the entire blowdown may last up to three hours.[14] One blowdown vents 15 MCf gas to atmosphere on average. Isolation valves leak about 1.4 Mcf/hr on average through open blowdown vents.[15]

It is not possible to know what exactly would be emitted in a given natural gas compressor station blowdown as there is no data available. We know that it will include whatever is in the pipeline when the blowdown occurs. This would undoubtedly include the constituents of natural gas: methane, ethane, etc., and various additional constituents would be present during different episodes. We are especially concerned about the presence of radioactive material during a blowdown. Anecdotally, there are reports of odors and burning eyes, headaches and coughing associated with the events.[16]

An exposure to blowdown concentrations of contaminants would have different health implications than a long-term lower level exposure (i.e. yearly average) to the same contaminants when the compressor is on line.

Accidents

In addition to planned emissions, fugitive emissions and blowdowns there is also the possibility of accidents at the compressor station. There are no central national or state inventories of compressor station accidents that we were able to locate. In their absence we turned to local news accounts of individual accidents (which are generally in the form of fires). Without knowing what precisely is in the pipeline nor what else (if anything) may be housed on the site, it is not possible to estimate emissions from a fire at the compressor station. The possibility, however, is very real. A gas compressor station exploded near Godley, TX. That fire destroyed the compressor station where it started and also the one next to it. The fire burned for several hours.[17] In a compressor station fire in Madison County, TX volunteer firefighters from four towns were dispatched to the site. First responders blocked roads near the site and evacuated three homes.[18] In Corpus Christi, TX a fire broke out at a compressor station which then spread to nearby brush before being extinguished.[19]

The possibility of fire or other accidents raises the concern over whether the localities surrounding a compressor station have the resources available to contain a fire or explosion adequately and whether first responders and hospitals are able to care for injured workers or others nearby or whether an evacuation plan could be implemented. In Wheeler County, TX four contractors were performing maintenance activities near a compressor station when a flash fire occurred. The workers were brought to a nearby hospital. Two were treated and released; the other two were transferred to a burn unit in Lubbock.[20] In Carbon County, UT an explosion and fire damaged a natural gas compressor station and other buildings on the site injuring two workers and engulfing the facility in flame. Firefighters from every city in the county responded to the emergency. Injured workers had to be evacuated by medical helicopters.[21]

Overall, there is little information on the division of responsibility between the company operating the facility and the locality. This should be clarified.

The question of radioactivity

A 2008 publication of the International Association of Oil & Gas Producers has laid out the discussion on radioactive material in the natural gas extraction and production process.

> During the production process, naturally occurring radioactive material (NORM) flows with the oil, gas and water mixture and accumulates in scale, sludge and scrapings. It can also form a thin film on the interior surfaces of gas processing equipment and vessels. The level of NORM accumulation can vary substantially from one facility to another depending on geological formation, operational and other factors.
>
> [R]adionuclides such as Lead-210 and Polonium-210 can … be found in pipelines scrapings as well as sludge accumulating in tank bottoms, gas/oil separators, dehydration vessels, liquid natural gas (LNG) storage tanks and in waste pits as well as in crude oil pipeline scrapings.[22]

The gas which flows through the pipeline likely carries gaseous radon with it, and as radon decays within the pipeline, the solid daughter elements, polonium and lead, accumulate along the interior of the pipes. There is a concern that the gas transiting, and being compressed and regulated, will have radioactivity levels which will put at risk not only the workers at these stations and along the pipeline, but potentially also to the residents.[23] Radon, a gas, has a short half-life (3.8 days) but its progeny are lead and polonium, and these are toxic and have relatively long half-lives of 22.6 years and 138 days respectively.[24] There is no data that we can turn to in order to assess the risk of radioactive exposures in our community.

Health risks from relevant air contaminants

Averages, peaks and health events

As stated previously, one of our primary concerns is the poor fit of a *tons per year* measurement to the assessment of risk to the public's health near a compressor station. Furthermore, the National Ambient Air Quality Standards (NAAQS) used as a benchmark for air quality were not created to assess the air quality and safety in a small geographic area with fluctuating emissions. NAAQS effectively address regional air quality concerns. But these standards do not adequately assess risk to human health for residents living in close proximity to polluting sources such as unconventional natural gas development (UNGD) sites, where emissions can be highly variable.

Generally, it has been shown that:

1. Current protocols used for assessing compliance with ambient air standards do not adequately determine the intensity, frequency or durations of the actual

human exposures to the mixtures of toxic materials released regularly at UNGD sites, including compressor stations.
2. The typically used periodic 24-hour average measures can underestimate actual exposures by an order of magnitude.
3. Reference standards are set in a form that inaccurately determines health risk because they do not fully consider the potential synergistic combinations of toxic air emissions.[25]

Thus estimates of yearly totals of contaminants released by a compressor station do not allow for an assessment of the physiological impact of those emissions on individuals.

NAAQS reflects what, over a region, over time, is deemed safe population-wide. This is very different than what is safe within for instance 1200 feet of this compressor station. As already stated, averaging over a year can wash out important higher spikes in emissions (thus exposures) that may occur at various points throughout the year. These high spikes can put residents at risk for illnesses caused by air toxics.

Toxicity and characterization of exposures

Toxicity of a chemical to the human body is determined by the concentration of the agent at the receptor where it acts. This concentration is determined by the intensity and duration of the exposure. All other physiological sequelae follow from the interaction between agent and receptor. Once a receptor is activated, a health event might be produced immediately or in as little as one to two hours.[26] [27] In some instances, where there is a high concentration of an agent, a single significant exposure can cause injury or illness. This is the case in the instance of an air contaminant induced asthma event. On the other hand, after an initial exposure, future exposures might compound the impact of the first one, in time, producing a health effect. Repeated exposures will increase, for instance, the risk for ischemic heart disease.[28]

Peak exposures

Researchers have demonstrated the wisdom of looking at peak exposures as compared to averages over longer periods of time. Darrow et al (2011) write that sometimes peak exposures better capture relevant biological processes. This is the case for health effects that are triggered by, short-term, high doses. They write, “Temporal metrics that reflect peak pollution levels (e.g., 1-hour maximum) may be the most biologically relevant if the health effect is triggered by a high, short-term dose rather than a steady dose throughout the day. Peak concentrations … are frequently associated with episodic, local emission events, resulting in spatially heterogeneous concentrations….”[29]

Delfino et al (2002) posited that maxima of hourly data, not 24-hour averages, better captured the risks to asthmatic children, stating, “it is expected that biologic responses may intensify with high peak excursions that overwhelm lung defense mechanisms.”

Additionally, they suggest that "[o]ne-hour peaks may be more influenced by local point sources near the monitoring station that are not representative of regional exposures…."[30]

Because episodic high exposures are not typically documented and analyzed by researchers and public agencies, natural gas compressor stations emissions are rarely correlated with health effects in nearby residents. However, examination of published air emission measurements shows the very real potential for harm from industry emissions.[31] Reports of acute onset of respiratory, neurologic, dermal, vascular, abdominal, and gastrointestinal sequelae near natural gas facilities contrast with research that suggests there is limited risk posed by unconventional natural gas development.

Health Effects from exposures to VOCs

VOCs, present at compressor station construction and operation, are a varied group of compounds which can range from having no known health effects to being highly toxic. Short-term exposure can cause eye and respiratory tract irritation, headaches, dizziness, visual disorders, fatigue, loss of coordination, allergic skin reaction, nausea, and memory impairment. Long-term effects include loss of coordination and damage to the liver, kidney, and central nervous system. Some VOCs, such as benzene, formaldehyde, and styrene, are known or suspected carcinogens.[32] The case for elevated risk of cancer from UNGD VOC exposure has been made by McKenzie et al (2012) and others.[33]

The inhalation of the VOC, benzene, produces a number of risks including

> [acute (short-term)] drowsiness, dizziness, headaches, as well as eye, skin, and respiratory tract irritation, and, at high levels, unconsciousness. Chronic (long-term) inhalation exposure has caused various disorders in the blood, including reduced numbers of red blood cells and aplastic anemia, in occupational settings. Reproductive effects have been reported for women exposed by inhalation to high levels, and adverse effects on the developing fetus have been observed in animal tests. Increased incidence of leukemia (cancer of the tissues that form white blood cells) have been observed in humans occupationally exposed to benzene. EPA has classified benzene as known human carcinogen for all routes of exposure.[34]

Benzene, which is documented at compressor stations by the States of Pennsylvania and Texas, carries its own risk, including risk for cancer.[35] [36] There is growing evidence that benzene is associated with childhood leukemia. Benzene affects the blood-forming system at low levels of occupational exposures, and there is no evidence of a threshold. It has been argued in the literature that "[t]here is probably no safe level of exposure to benzene, and all exposures constitute some risk in a linear, if not supralinear, and additive fashion.[37]

Another substance that is detected near compressor stations is methylene chloride.

According to the EPA:

> The acute (short-term) effects of methylene chloride inhalation in humans consist mainly of nervous system effects including decreased visual, auditory, and motor functions, but these effects are reversible once exposure ceases. The effects of chronic (long-term) exposure to methylene chloride suggest that the central nervous system (CNS) is a potential target in humans and animals. Human data are inconclusive regarding methylene chloride and cancer. Animal studies have shown increases in liver and lung cancer and benign mammary gland tumors following the inhalation of methylene chloride.[38]

The VOC formaldehyde is also considered a Hazardous Air Pollutant (HAP) by the US EPA (EPA).[39] It is one of the emissions chemicals that the natural gas development industry is required to report, for instance to the PA DEP. According to these reports, compressor stations are the highest UNGD source for formaldehyde.[40] For the year 2012, emissions of formaldehyde from compressor stations in Pennsylvania ranged from 0.0 TPY to 22.5 TPY. [41]

A recent study of air emissions in the Barnett shale region of Texas found concentrations of formaldehyde at sites with large compressor stations.[42] Some of these concentrations were greater than the Texas Commission on Environmental Quality's health protective levels (page 62). Formaldehyde was one of 101 chemicals found in association with methane in this study. The research showed that aromatics in particular were associated with compressor stations.

Air exposures to formaldehyde target the lungs and mucous membranes and in the short-term can cause asthma-like symptoms, coughing, wheezing, and shortness of breath. The EPA classifies it as a probable human carcinogen.[43] The World Health Organization classifies it as carcinogenic to humans.[44] It has also been associated with childhood asthma.[45] The California Office of Environmental Health Hazard assessment (OEHHA) has "identified formaldehyde as a Toxic Air Contaminant and gives it an inhalation Reference Exposure Level (REL) of 55 ug/m^3 for acute exposures and 9 ug/m^3 for both 8-hour and chronic exposures.[46] The acute REL is 74 ppb based on irritation of asthmatics.[47] It has also been linked with adverse pregnancy outcomes and reproductive and developmental toxicity.[48]

More recent investigations on formaldehyde near compressor stations are focused on the chemical reaction between methane and sunlight.[49] While it is well known that stationary compressor station engines emit formaldehyde, it is less well known that formaldehyde may also be formed at these sites through this chemical reaction. While the research is ongoing, it suggests that health hazards associated with formaldehyde may be greater than previously thought. Because reported health symptoms near compressor stations, such as respiratory impacts and shortness of breath, can be caused by exposure to formaldehyde, targeted monitoring of this chemical at these sites would be recommended.

Effects from exposure to particulate matter

In addition to the VOC exposure presented above, PM2.5 also poses a significant health concern and interacts with the airborne VOCs increasing their impact. In fact, at a compressor station PM2.5 may pose the greatest threat to the health of nearby residents. Fine particles are expected to reach a total of 1.136 tons for 2015 and 2016.

The size of particles determines the depth of inhalation into the lung; the smaller the particles are, the more readily they reach the deep lung. Particulate matter (PM10, PM2.5 and ultrafine PM), in conjunction with other emissions, are at the core of concern over potential effects of UNGD.

High particulate concentrations are of grave concern because they absorb airborne chemicals in their midst. The more water soluble the chemical, the more likely it is to be absorbed onto a particle. Larger sized particles are trapped in the nose and moist upper respiratory tract thereby blocking or minimizing their absorption into the blood stream. The smaller PM2.5 however, is more readily brought into the deep lung with airborne chemicals and from there into the blood stream. As the particulates reach the deep lung alveoli the chemicals on their surface are released at higher concentrations than they would in the absence of particles. The combination of particles and chemicals serves, in effect, to increase in the dose of the chemical. The consequences are much greater than additivity would indicate; and the physiological response is intensified. Once in the body, the actions between particles and chemicals are synergistic, enhancing or altering the effects of chemicals in sometimes known and often unknown ways.[50]

Reported clinical actions resulting from PM2.5 inhalation affect both the respiratory and cardiovascular systems. Inhalation of PM2.5 can cause decreased lung function, aggravate asthma symptoms, cause nonfatal heart attacks and high blood pressure.[51] Research reviewing health effects from highway traffic, which, like UNGD, has especially high particulates, concludes, "[s]hort-term exposure to fine particulate pollution exacerbates existing pulmonary and cardiovascular disease and long-term repeated exposures increases the risk of cardiovascular disease and death."[52] PM2.5, it has been suggested, "appears to be a risk factor for cardiovascular disease via mechanisms that likely include pulmonary and systemic inflammation, accelerated atherosclerosis and altered cardiac autonomic function. Uptake of particles or particle constituents in the blood can affect the autonomic control of the heart and circulatory system."[53]

Ultrafine particles (<0.1) get less attention in the literature than PM2.5 but is found to have high toxic potency.[54] These particles readily deposit in the airways and centriacinar region of the lung.[55] Research suggests increases in ultrafine particles pose additional risk to asthmatic patients.[56] Ultrafine particles are generally produced by combustion processes. They, along with the larger PM2.5, are found in diesel exhaust.

Diesel is prevalent during the construction phase of compressor station site. High levels of diesel exhaust from construction machinery as well as trucks increase the level of respirable particles. Health consequences of diesel exposure have been widely studied and include immediate and long term health effects. Diesel emissions can irritate the eyes, nose, throat and lungs, and can cause coughs, headaches, lightheadedness and nausea. Short-term exposure to diesel exhaust also causes inflammation in the lungs, which may aggravate chronic respiratory symptoms and increase the frequency or intensity of asthma attacks. Long-term exposure can cause increased risk of lung cancer.[57]

PM2.5 acute effects

There is an abundance of research on the health effects of short term PM2.5 exposure. Mills et al demonstrate that one to two hours of a diesel exhaust exposure, which occurs during the construction phase of development, includes reduced brachial artery diameter and exacerbation of exercise-induced ST-segment depression in people with pre-existing coronary artery disease; ischemic and thrombotic effects in men with coronary heart disease;[58] and is associated with acute endothelial response and vasoconstriction of a conductance artery.[59] Fan He et al. suggest that health effects can occur within 6 hours of elevated PM2.5 exposures, the strongest effects occurring between 3 and 6 hours. Such an acute effect of PM2.5 may contribute to acute increase in the risk of cardiac disease, or trigger the onset of acute cardiac events, such as arrhythmia and sudden cardiac death.[60]

Numerous epidemiological studies have demonstrated a consistent link between particulate matter and increased cardiopulmonary morbidity and mortality (Brook et al. 2004; Mann et al. 2002; Pope et al. 2002; Samet et al. 2009; Schwartz 1999).[61] Previous studies have suggested that PM2.5 exposure is significantly associated with increased heart rate and decreased heart rate variability (HRV; Gold et al., 2000; He et al. 2010; Liao et al. 1999; Luttmann-Gibson et al. 2006; Magari et al. 2001; Park et al. 2005).

In addition to short term exposures and associated effects, there is evidence of health impacts from long-term exposures.[62] An HIA reviewing data from a number of European cities found that nearly 17,000 premature deaths from all causes, including cardiopulmonary deaths and lung-cancer deaths, could be prevented annually if long-term exposure to PM2.5 levels were reduced. Equivalently, this reduction would increase life expectancy at age 30 by a range between one month and more than two years in the study cities. A Canadian national cohort study found positive and statistically significant associations between non-accidental mortality and estimates of PM2.5, the strongest association being with ischemic heart disease. Associations in this study were with concentrations of PM2.5 as low as only a few micrograms per cubic meter.[63] Research has also shown that there is an association between PM2.5 and hospitalization for COPD in elderly people.[64]

There is also a considerable literature on the health effects specifically from diesel emission that include PM2.5 along with chemical components. Mills et al conclude that even dilute diesel emissions can induce risk and point to ischemic and thrombotic mechanisms for the adverse cardiovascular events associated with diesel exposure.[65]

After an extensive review the EPA concluded that

> long-term inhalation exposure is likely to pose a lung cancer risk to humans. Estimation of cancer potency from available epidemiology studies was not attempted…. A noncancer chronic human health hazard is inferred from rodent studies showing dose-dependent inflammation and histopathology in rats. Short-term exposures were noted to cause irritation and inflammatory symptoms of a transient nature these being highly variable across an exposed population. The assessment also indicates that there is emerging evidence fro the exacerbation of existing allergies and asthma symptoms.[66]

<u>Children, pregnant women and air contaminants</u>

Children and pregnant women are especially sensitive to pollution. Many studies confirm a range of adverse effects of air pollution on children's lung function and respiratory symptoms, especially for asthmatics. Recent studies have found statistically significant associations between the prevalence of childhood asthma or wheezing and living very close to high volume vehicle roadways.[67] Other research aimed specifically at children’s PM2.5 exposure has found that PM2.5 and several of its components have important effects on hospital admissions for respiratory disease, especially pneumonia. The authors count among the sources for this exposure diesel exhaust, motor vehicle emissions, and fuel combustion processes.[68]

Health effects have been found in pregnant women from high particulate highway pollution. Such particle pollution “may provoke oxidative stress and inflammation, cause endocrine disruption, and impair oxygen transport across the placenta, all of which can potentially lead to or may be implicated in some low birth weight … and preterm births.” The consequences do not stop with low birth weight and preterm births because these conditions can negatively affect health throughout childhood and into adulthood.[69]

<u>Mixtures and sequential exposures</u>

Mixtures of pollutants are a critically important topic in addressing the public health implications of UNGD broadly and compressor stations in this case. While this report has focused primarily on three pollutants (VOCs, formaldehyde as one example, and PM2.5), in fact, a very large number of chemicals are released together. Medical reference values are not able to take the complex nature of the shale environment, its multiple emissions and interactions into full consideration.[70] Although the shale gas industry is not unique in emitting multiple pollutants simultaneously, this industry is unique in doing so as close as 500 feet from residences.

Chemicals that reach the body interfere with metabolism and the uptake and release of other chemicals, be they vitally important biochemical produced and needed by the body or other environmental chemicals with potentially toxic effects. Some chemicals attack the same or similar target sites creating an additive effect. This is the case with chemicals of similar structure such as many in the class of VOCs. Some mixtures like PM and VOC act synergistically to increase the toxicity of the chemicals. Other chemicals released environmentally are rapidly absorbed and slowly excreted. These slowly excreted chemicals will interfere with subsequent actions of chemicals because the body has not yet cleared the effects from the earlier exposure.

Noise

Excessive noise has been associated with an array of psychological and physical effects. A review article on noise exposure and health risk published in *Noise and Health* claims that the evidence for a causal relationship between community or transportation noise and cardiovascular risk has risen in recent years. In sum, the author finds limited evidence for a causal relationship between noise and biochemical effects; limited or sufficient evidence for hypertension; and sufficient evidence for ischemic heart disease.[71]

According to a World Health Organization assessment of research, excessive noise can also increase risk of cognitive impairment in children, sleep disturbance, tinnitus, and high levels of annoyance.[72] Researchers have found associations between elevated sound levels – including community sounds levels – and hearing loss, reduced performance and aggressive behavior.[73] Additionally some attention is being paid to the health effects of vibration exposure which is connected with but distinct from noise itself.[74]

Noise exposures are associated with construction activities and during blowdown episodes. As with air exposures, the periods of extreme exposures (in this case noise exposures) can cause different and sometimes more serious effects than low-level exposures.

Summary

In sum, we know that a number of different chemicals as well as PM2.5 are present during the construction phase of compressor stations and they are present in close proximity to compressor stations that are on line. Some, although not all, have documented health effects on vulnerable populations and on the population at large. What we do not know is the precise mix and concentration of chemicals that will be released into the air. Without that information it is not possible to assess the compressor station's full impact on area residents.

Reported health effects specific to compressor stations

There is a growing body of research on emissions and health impacts from UNGD generally, though few studies specifically address health impacts from compressor stations. This is partly due to the fact that many compressors are sited in proximity to other UNGD sites such as well pads, impoundments, condensate tanks and processing stations. As the infrastructure for transporting natural gas continues to expand, more pipelines, metering stations and compressor stations will be sited away from other UNGD facilities.

Recent research that has been conducted near compressor stations in different parts of the country shows consistencies in the types of symptoms experienced by those living near these sites. These symptoms are associated with health impacts on respiratory, neurological and cardiovascular body systems. It should be noted that in each of the studies cited here health survey forms were filled out by residents and, as such, the findings are self-reported. To date there have been no epidemiological studies performed to identify health impacts from compressor stations.

A peer-reviewed article, *Investigating Links Between Shale Gas Development And Health Impacts Through A Community Survey Project In Pennsylvania* (2014) is one of the few publications that explicitly addresses health impacts from compressors.[75] The report states:

> In the Pennsylvania study, distance to industrial sites correlated with the prevalence of health symptoms. For example, when a gas well, compressor station, and/or impoundment pit were 1500-4000 feet away, 27 percent of participants reported throat irritation; this increased to 63 percent at 501-1500 feet and to 74 percent at less than 500 feet. At the farther distance, 37 percent reported sinus problems; this increased to 53 percent at the middle distance and 70 percent at the shortest distance. Severe headaches were reported by 30 percent of respondents at the farther distance, but by about 60 percent at the middle and short distances. [76] P.62

Age groups also responded differently in terms of health symptoms:

> Among the youngest respondents (1.5-16 years of age), for example, those within 1500 feet experienced higher rates of throat irritation (57% vs. 69%) and severe headaches (52% vs. 69%). It is also notable that the youngest group had the highest occurrence of frequent nosebleeds (perhaps reflective of the more

> sensitive mucosal membranes in the young), as well as experiencing conditions not typically associated with children, such as severe headaches, joint and lumbar pain, and forgetfulness.
>
> Among 20- to 40-year-olds, those living within 1500 feet of a facility reported higher rates of nearly all symptoms; for example, 44 percent complained of frequent nosebleeds, compared to 29 percent of the entire age group. The same pattern existed among 41- to 55-year-olds with regard to several symptoms (e.g., throat and nasal irritation and increased fatigue), although with smaller differences and greater variability than in the other age groups.
>
> The subset of participants in the oldest group (56- to 79-year-olds) living within 1500 feet of facilities had much higher rates of several symptoms, including throat irritation (67% vs. 47 %), sinus problems (72% vs. 56%), eye burning (83% vs. 56%), shortness of breath (78% vs. 64%), and skin rashes (50% vs. 33%).
>
> In sum, while these data do not prove that living closer to oil and gas facilities causes health problems, they do suggest a strong association since symptoms are more prevalent in those living closer to facilities than those living further away. Symptoms such as headaches, nausea, and pounding of the heart are known to be the first indications of excessive exposure to air pollutants such as VOCs [36], while the higher level of nosebleeds in the youngest age group is also consistent with patterns identified in health survey projects in other states [9, 10]." P.64

Earthworks, a non-profit organization, conducted the Pennsylvania study referred to above, (Gas Patch Roulette 2012) in which they surveyed residents about health symptoms and conducted air and water tests near residences in Pennsylvania and New York[77]. In their report, specific mention is given of a residence 800 feet from a compressor station. Health symptoms experienced by the residents (parents and children) were extreme tiredness, severe headaches, runny noses, sore throats and muscle aches, as well as dizziness and vomiting by one individual.

Earthworks also conducted a health survey in Dish, Texas in 2009.[78] The health symptoms reported to be associated with compressors were: burning eyes, nausea, headaches, running nose, sore throat, asthma, sinus problems and bronchitis. Odors experienced by residents near compressor stations were described as: sulfur smell, odorized natural gas, burnt wire, strong chemical-like smell and ether.

Wilma Subra[79], an environmental chemist and consultant who is on the Earthworks Board of Directors, has compiled information on health symptoms experienced near compressor stations based on her research with communities concerned about health impacts from UNGD[80]. Subra has served as Vice-Chair of the Environmental Protection Agency National Advisory Council for Environmental Policy and Technology (NACEPT), and recently completed a five year term on the National Advisory Committee of the U.S. Representative to the Commission for Environmental Cooperation and a six year term on the EPA National Environmental Justice Advisory Council (NEJAC) where she served as a member of the Cumulative Risk and Impacts Working Group of the NEJAC Council. While her research on health impacts associated with compressor stations is reported back to communities, most of the data shown here have not been published in peer-reviewed journals (she is an author on the above-mentioned peer-reviewed article on Pennsylvania data).

Subra has reported the following health impacts in association with compressor stations:

Table 2. Most Prevalent Medical Conditions In Individuals Living in Close Proximity to Compressor Stations and Metering Stations

Medical Conditions:	% of Individuals (71)
Respiratory Impacts	58
Throat Irritation	55
Weakness and Fatigue	55
Nasal Irritation	55
Muscle Aches & Pains	52
Vision Impairment	48
Sleep Disturbances	45
Sinus Problems	42
Allergies	42
Eye Irritation	42
Joint Pain	39
Breathing Difficulties	39
Severe Headaches	39
Swollen & Painful Joints	32
Frequent irritation	32

The full list of health impacts “Reported by Community Members Living 50 feet to 2 miles from Compressor Stations and Gas Metering Stations Along Gas Transmission Pipelines” is available at the Luzerne County Citizens for Clean Air website[81]. It is notable that Subra reports that 61% of health impacts are associated with the chemicals present in the air that were in excess of short and long term effects screening levels.

Subra further reports that the following units at compressor stations and gas metering stations release emissions into the air:

Compressor Engines

Compressor Blowdowns

Condensate Tanks
Storage Tanks
Truck Loading Racks
Glycol Dehydration Units
Amine Units
Separators
Fugitive Emission Sources

She reports that 90% of individuals surveyed reported experiencing odor events from these facilities. Based on her analysis, the following health symptoms are associated with the chemicals detected in the air at compressor stations:

Allergies
Persistent Cough
Shortness of Breath
Frequent Nose Bleeds
Sleep Disturbances
Joint Pain
Difficulty in Concentrating
Nervous System Impacts
Forgetfulness
Sores and Ulcers in Mouth
Thyroid Problems

Subra reports that both the construction and production phases of compressor stations can cause acute and chronic impacts. In the construction phase impacts come from diesel truck emissions and from dust particles. In the production phase impacts are derived from constant emissions, venting, blowdowns, accidents/malfunctions and from the effects of noise, light and stress. She considers respiratory health impacts of particular concern, and vulnerable groups such as pregnant women, children, the elderly and sensitive individuals to be at greatest risk. Acute and chronic health impacts that Subra has documented are listed below.

Acute Health Impacts Experienced by Individuals Living and Working near Compressor Stations

Tense and nervous
Joint and muscle aches and pains
Vision Impairment
Personality changes
Depression, Anxiety
Irritability
Confusion
Drowsiness
Weakness
Irregular Heartbeat
Irritates skin, eyes, nose, throat and lungs
Respiratory impacts
Sinus problems
Allergic reactions
Headaches
Dizziness, Light headedness
Nausea, Vomiting
Skin rashes
Fatigue
Weakness

Chronic Health Impacts Experienced by Individuals Living and Working near Compressor Stations

- Damage to Liver and Kidneys
- Damage to Lungs
- Damage to Cardiovascular System
- Damage to Developing Fetus
- Reproductive Damage
- Mutagenic Impacts
- Developmental Malformations
- Damage to Nervous System
- Brain Impacts
- Leukemia
- Aplastic Anemia
- Changes in Blood Cells
- Impacts to Blood Clotting Ability

Radioactive elements: a long-term health threat

The possibility of exposure to radiation from natural gas pipelines and compressor stations is also a concern, especially for long-term health effects. The New York public health group, Concerned Health Professionals of New York, describes the problem in their report, Compendium Of Scientific, Medical, And Media Findings Demonstrating Risks And Harms Of Fracking (Unconventional Gas And Oil Extraction) (July 10, 2014): "Unsafe levels of radon and its decay products in natural gas produced from the Marcellus Shale, known to have particularly high radon content, may also contaminate pipelines and compressor stations, as well as pose risks to end-users when allowed to travel into homes."(P.5). Health impacts from exposure to radioactive materials in compressor station emissions have not been documented, but the risk of exposure to these carcinogens are a serious public health concern.

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