

Southwest Pennsylvania Environmental Health Project Technical Reports

What EHP Has Learned About Health Impacts Related to Unconventional Natural Gas Development (UNGD)

Southwest Pennsylvania's unconventional natural gas development (UNGD) activities expanded rapidly after 2007. As residents began reporting the onset of new health symptoms in association with these activities, concern grew regarding the potential adverse health impacts of this new technology.

Since 2012, EHP has advised, educated, or evaluated over 1,000 individuals. The most in-depth evaluations occur in encounters with the nurse practitioner. During these meetings the nurse practitioner reviews a comprehensive health assessment form that includes detailed information on potential exposure sources, health symptoms, and medical history. In addition to other potential occupational, recreational or household exposure sources, the health assessment form also includes information on household water sources and water use, documenting any changes noted in water quality and any water testing results.

When reviewing the health symptoms section, the nurse practitioner records information on the timing of onset, worsening, or resolution of symptoms. In response to the information on the health assessment form, the nurse practitioner advises the client on the appropriateness of additional evaluation, steps that can be taken to improve overall health and wellness, and measures that can be employed to reduce potentially hazardous exposures.

Individuals and families have consulted the EHP nurse practitioner for a variety of reasons. Some have been concerned that recent onset health symptoms may be related to nearby UNGD activities. Others have been without current symptoms, but concerned that nearby or planned UNGD activities may result in future health problems. Some have been interested in learning more about UNGD. In addition to residents of SWPA, the nurse practitioner has been consulted by individuals from at least five other states.

Activities associated with UNGD inevitably emit hazardous air emissions and sometimes result in water contamination. Increases in noise and traffic predictably occur. Conflict between neighbors and even within families has arisen. People worry

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about both the financial and health impacts that drilling activities will have on them and their families.

Although the EHP health assessment process was not designed as a research project, after several years of evaluating individuals with health concerns related to UNGD, EHP recognized that an analysis of the cumulative information recorded during these consultations could contribute to the growing understanding of the health impacts of UNGD. This report summarizes what EHP has learned regarding new onset health symptoms experienced by residents living in proximity to UNGD activity. The information is presented in the context of recognized health effects of air, water, and noise exposures produced by UNGD activity.

What is Known About Air Exposures

The potential health effects of many of the chemicals emitted from well pads, compressor stations, production facilities and diesel fueled vehicles are known from studies of other settings where individuals experienced environmental exposures (1). These settings have included living close to industrial facilities, hazardous waste sites, or heavily trafficked highways.

The recognized air emissions from UNGD (2) may result in acute health symptoms as well as long-term health problems. Individuals are exposed to air pollutants primarily through inhalation, but also may be exposed through contact with skin or by ingestion of contaminated agricultural products. Air emissions can be constant, intermittent or transient, potentially contributing to constant, intermittent or transient symptoms.

Exposure to many of the chemicals emitted from UNGD result in similar acute health effects. For example, even at low levels of exposure, a number of these chemicals have irritant properties, which can affect the eyes, nose, sinuses, throat, lungs or skin. Individuals have varying sensitivities to these chemicals. People with pre-existing respiratory or cardiac problems are most likely to develop acute symptoms.

The potential long-term health effects of exposures to chemicals varies based on the chemical or chemical mixtures involved. In general, the potential to develop a serious health condition known to be associated with a particular chemical increases as the intensity and duration of exposure increase. The potential long-term health effects of the exposure to some of the chemicals or mixtures of chemicals, are not well studied.

In general, vulnerable populations such as children, pregnant women, the elderly and individuals with pre-existing medical conditions are most susceptible to health impacts from chemical exposures.

The accompanying chart on page 3 describes some potential acute health symptoms and long-term health effects that might result from environmental exposure to low levels of chemicals recognized to be emitted from UNGD activities. The table does not address all of the health effects that might be experienced at higher levels of exposures such as encountered in an occupational setting or an acute poisoning event. For example, as indicated in the chart, exposures to small increases in carbon monoxide in the air, such as might result from living near a well pad, are shown in experimental studies to reduce exercise tolerance and increase risk for heart problems in susceptible individuals. On the other hand, it is well known that high levels of carbon monoxide such as might occur indoors from an improperly vented heating appliance, can be fatal. The chart does not address these effects as this level of exposure would not be expected to result just from living in proximity to UNGD activity.

Chart 1. Potential Health Effects Due to Inhalation of Low-Level Environmental Air Contaminants Generated by Unconventional Natural Gas Development (UNGD) Related Activities*

Chemical	Sources	Short term Exposures, Acute Health Symptoms	Long term Exposures, Chronic Health Effects
Volatile Organic Chemicals (VOC's)	Well pads Compressor Stations Processing Facilities	Varies with individual chemical. See following examples: Benzene, Ethyl Benzene, Toluene, Xylene	Varies with individual chemical. See following examples.
Benzene (3)	Same as above	Headache, dizziness	Aplastic anemia, leukemia
Ethyl benzene (4)	Same as above	Eye and throat irritation	Possible carcinogen
Toluene (5)	Same as above	Headaches, sleepiness, confusion	Possible permanent neurological problems
Xylenes (6)	Same as above	Eye, nose, throat , and skin irritation	Possible permanent neurological effects.
Methylene Chloride (7)	Well pads	Decreased attentiveness and decreased hand-eye coordination	Cancer
Formaldehyde (8)	Well pads Compressor Stations Processing Facilities	Nose and eye irritation, impaired short term memory, asthma attacks	Asthma, eczema, nasal and throat cancer
Diesel Exhaust (contains VOC's and PM2.5) (9)	Well pads Compressor Stations Truck traffic	Eye, nose, throat and lung irritation. Headaches, dizziness, nausea	Worsening respiratory disease, lung cancer
Hydrogen sulfide (10)	Well pad	Eye, nose, and throat irritation. Nausea. Asthma attacks.	Eye, nose, and throat irritation. Worsening asthma.
Polycyclic Aromatic Hydrocarbons (11) (12)	Well pads Compressor Stations Processing Facilities	Eye and skin irritation, asthma attacks, acute cardiac events, adverse effects on developing fetus.	Contribute to the development or worsening of pulmonary or cardiac disease. Lung, skin, bladder cancer.
Particulate Matter 2.5 (PM2.5) (13)	Well pads Compressor Stations Processing Facilities	Asthma attacks, acute bronchitis, heart attacks in individuals with cardiac disease	Reduced lung function, chronic bronchitis
Ozone (14)	Created by chemical reactions between NOx and VOC's in the presence of sunlight.	Chest pain, coughing, throat irritation, congestion. Increased symptoms in bronchitis, emphysema, and asthma.	Contributes to development of chronic lung disease and worsens pre-existing bronchitis, emphysema, and asthma.
Radon (15)	Naturally occurring in shale. Contained in produced gas	None	Lung cancer
Carbon monoxide (CO) (16)	Well pads Compressor Stations Processing Facilities	Decreased exercise tolerance, decreased vigilance, increased risk for cardiac ischemia in individuals with heart disease	Decreased exercise tolerance, decreased vigilance, increased risk cardiac ischemia
Nitrogen oxides (NOx) (17)	Well pads Compressor Stations Processing Facilities	Respiratory symptoms, worsening asthma	Respiratory disease, worsening heart disease

**Chart does not include all additional potential health effects occurring with higher level occupational exposures.*

Sources of Exposures:

- Well-pad: Includes well head, flaring, diesel powered equipment, produced water storage pits and tanks, vehicles.
- Compressor Stations: Located along natural gas pipelines to compress gas to a sufficient pressure to keep the gas moving.
- Processing Facilities: Clean raw natural gas by removing impurities and separating out non-methane hydrocarbons.

What is Known About Water Exposure

Most UNGD activity occurs in rural areas where families rely on private wells for water and where there is no mandatory monitoring of water quality. Typically, when water is tested, the Environmental Protection Agency's Drinking Water Standards (18) are referenced to determine whether the water is safe to drink.

When water is contaminated, users can be exposed in a variety of ways. The most common exposure is through ingestion, either from drinking the water (or beverages containing water) or using the water for cooking. Exposure can also occur from contact with the skin while bathing or showering. In addition, for those chemicals which volatilize from water, exposure can occur through inhalation any time the water is run for any purpose.

Both the PADEP (19) and the EPA (20) acknowledge that UNGD activities have contaminated wells. In theory, wells might be contaminated with any of the chemicals used in hydraulic fracturing or from the chemicals existing in the shale layer which are brought to the surface as a result of hydraulic fracturing. The most likely sources of contamination are leaks in well casing, leaks or surface spills of waste water, or surface spills of chemicals (20).

In order to determine if UNGD activities have contaminated a well, the water must have been tested before and after drilling for the chemicals of concern. A laboratory typically only tests for those chemicals which have been selected in the request for testing. Unfortunately, tests for many of the UNGD chemicals which could potentially contaminate water are not included in routine water testing. In fact, for some chemicals, there are no standard tests available. For some chemicals for which there are standard tests, there are no corresponding EPA health guidelines to determine if the chemical poses a risk to health. Finally, since the oil and gas Industry is not required to identify all the chemicals used in UNGD activities, it is possible that some of these unidentified chemicals might contaminate water and never be tested for.

In addition to the challenges posed by the analysis of water samples, the conventional technique for collecting samples may lead to the loss of some chemicals of concern by allowing them to volatilize from the sample prior to analysis (21).

Given the challenges of detecting UNGD related water contamination, it is not surprising that families who noted obvious changes in their well water after UNGD activity began nearby, were subsequently informed that water tests were acceptable.

Without a more in depth understanding of UNGD related water contamination, it is impossible to compile a list of all the potential acute and long term health effects. However, as noted in the results section, individuals who

noticed changes in their well water or who had documented contamination experienced more health symptoms than those who did not.

What is Known About Noise Exposures

The activities of well pad construction, well drilling and hydraulic fracturing are conducted twenty-four hours a day, seven days a week. In addition to the noise from the diesel trucks servicing the well pad, the onsite operations create constant loud noise for months at a time. The levels of noise experienced by residents living at various distances during different UNGD activities are indicated in the following table.

Source	Distance in Feet from Noise						Duration Activity (days)
	50	250	500	1000	1500	2000	
UNGD Activity							
Access Road Construction	89	75	69	63	59	57	3-7
Well Pad Construction	84	70	64	58	55	52	7-14
Vertical Drilling	79	64	58	52	48	45	(Total drilling, single well) 28-35
Horizontal Drilling	76	62	56	50	47	44	
Hydraulic Fracturing	104	90	84	78	74	72	(Single well) 2-5

Table 1. Composite Noise Levels of UNGD Activities at Various Distances (SPL/dBA) as Compiled from NYDEC SGEIS 2011 (22)

Although the above noise levels could contribute to noise-induced hearing loss in workers in close proximity to the sources, individuals further away are at risk for non-auditory health effects. Noise levels above 40 decibels can easily result in sleep disturbance. Higher levels of environmental noise contribute to annoyance, decreased performance, elevation of blood pressure and cardiovascular disease (22).

Reported Health Impacts of UNGD Activities

In 2012, using data on measured air emissions from an unconventional gas well pad, McKenzie et al employed EPA methodology to estimate resulting health risks to individuals living in proximity to the well pad (23). They determined that residents living within ½ mile of the well pad were at increased risk of both cancer and non-cancer health effects as a result of the measured air emissions than those living further away. With regards to potential impacts of short-term (subchronic) exposures, the residents experienced an increase risk for respiratory, neurological, hematologic and developmental effects.

Also published in 2012 was a case series by Bamberger and Oswald documenting adverse health impacts of UNGD on families and their animals (24).

In 2013, published community surveys further documented the potential acute health impacts of UNGD activities (25) (26). Reported health effects included respiratory symptoms, rashes, nosebleeds and gastrointestinal symptoms.

In 2015, Rabinowitz et al published “Proximity to Natural Gas Wells and Reported Health Status: Results of a Household Survey in Washington County, Pennsylvania” (27). Rather than relying on self-selected participants

as in prior surveys, the authors randomly selected households to be surveyed. Survey results indicated that individuals living within one kilometer (approximately ½ mile) of unconventional natural gas wells experienced greater numbers of dermatological and upper respiratory symptoms than those living further away.

In 2016, Rasmussen et al published the first study of *diagnosed* (vs. self-reported) health conditions in relationship to exposure to UNGD activities (28). With access to emergency department and hospitalization data, as well as pharmacy information from the Geisinger Clinic the authors determined that increasing proximity to UNGD activities was associated with increasing risk for worsening asthma symptoms in individuals previously diagnosed with asthma.

A second study published in 2016 surveyed over 23,000 adult patients of the Geisinger Clinic regarding chronic sinusitis, migraine headache and fatigue symptoms (29). In comparison to respondents with no or minimal symptoms, respondents with current chronic rhinosinusitis (nose and sinus) symptoms, migraine headaches, and high levels of fatigue were more likely to reside in closer proximity to UNGD activities.

In summary, multiple published studies have suggested that individuals living in proximity to UNGD activities have an increased likelihood of experiencing health symptoms which have included upper and lower respiratory symptoms, headaches, skin symptoms, fatigue, and gastro-intestinal symptoms.

Methods

Based on the findings in the McKenzie and Rabinowitz articles discussed above, in reviewing the health symptoms experienced by individuals evaluated by the EHP nurse practitioner, the authors chose to focus on those residing within 1 kilometer (approximately ½ mile) of UNGD activities. For adults living in SWPA, distance from UNGD activities at the time of the intake (well pad, impoundment, compressor station) had previously been established using FracTracker (30). Individuals who had been evaluated by the nurse practitioner, but who were from out-of-state were excluded from the analysis due to greater difficulty in confirming proximity to UNGD activities. Individuals whose primary potential exposure to UNGD activity was occupational, rather than environmental, were also excluded from the analysis. Due to the differences in susceptibility and ability to report symptoms, as well as the small number, children who had been evaluated were additionally excluded from the analysis. Individuals were included regardless of whether or not they had experienced symptoms potentially attributable to UNGD activities. Individuals were only included if they had completed the entire lengthy assessment form.

Using the above criteria, 61 adult cases were eligible for the analysis. The de-identified assessment forms of these 61 individuals were reviewed by a physician specializing in occupational and environmental medicine and a research associate. Symptoms were considered to be potentially related to the nearby UNGD activity if the onset or worsening occurred after the onset of potential exposures and could not as easily be explained by alternative exposure sources or pre-existing medical conditions. New onset symptoms could be constant or intermittent. Transient symptoms were included only if associated with a particular UNGD exposure event, such as flaring or well contamination.

Results

The following table compiles the symptoms meeting the criteria delineated in the methods section above.

Table 2. Symptoms Temporally Related to UNGD Activity (n=61)

SYMPTOM CATEGORY	n	%	SYMPTOM	n	%
UPPER RESPIRATORY SYMPTOMS	39	64%			
			Nose or throat irritation	25	41%
			Sinus pain or infections	17	28%
			Nose bleeds	8	13%
CONSTITUTIONAL SYMPTOMS	33	54%			
			Sleep disruption	26	43%
			Fatigue	13	21%
			Weak or Drowsy	9	15%
NEUROLOGICAL SYMPTOMS	32	52%			
			Headache	25	41%
			Dizziness	11	18%
			Numbness	9	15%
			Memory loss	8	13%
PSYCHOLOGICAL SYMPTOMS	32	52%			
			Stress or anxiety	23	38%
			Irritable or moody	12	20%
			Worry	6	10%
LOWER RESPIRATORY SYMPTOMS	30	49%			
			Cough	21	34%
			SOB	19	31%
			Wheezing	14	23%
GASTRO-INTESTINAL SYMPTOMS	27	44%			
			Nausea	13	21%
			Abdominal pain	12	20%
EYE SYMPTOMS	23	38%			
			Itchy eyes	11	18%
			Painful or dry	10	16%
DERMATOLOGICAL SYMPTOMS	19	31%			
			Rash	10	16%
			Itching	7	11%
			Lesions or blisters	6	10%
CARDIAC SYMPTOMS	17	28%			
			Palpitations	9	15%
			Chest pain	6	10%
			Other cardiac symptoms	6	10%
HEARING CHANGES OR TINNITUS	10	16%			
			Hearing loss	3	5%
			Tinnitus	10	16%

MUSCULOSKELETAL	10	16%			
			Painful joints	9	15%
			Aches	7	11%
ENDOCRINE	7	11%			
			Hair loss	7	11%

Symptoms were also analyzed according to whether the interior household water source was identified to be, at least in part, from a private source such as a well or spring, or whether the household relied entirely on a public water source. In addition, symptoms in those users of private sources who had observed changes in post drilling water quality (with or without laboratory documentation of water contamination) were analyzed separately. (The source of water was unknown for 5 cases).

Table 3. Symptoms Temporally Related to UNGD Activity by Water Source

SYMPTOM CATEGORY	WATER SOURCE							
	ANY WATER SOURCE n=61		PUBLIC WATER n=15		PRIVATE SOURCE n=41		PRIVATE SOURCE WITH CHANGES n=24	
	n	%	n	%	n	%	n	%
UPPER RESPIRATORY	39	64%	10	67%	27	66%	19	79%
CONSTITUTIONAL	33	54%	9	60%	23	56%	16	67%
NEUROLOGICAL	32	52%	6	40%	24	59%	16	67%
PSYCHOLOGICAL	32	52%	11	73%	19	46%	14	58%
LOWER RESPIRATORY	30	49%	7	47%	21	51%	14	58%
GASTROINTESTINAL	27	44%	5	33%	22	54%	14	58%
EYE	23	38%	3	20%	19	46%	13	54%
DERMATOLOGICAL	19	31%	3	20%	16	39%	15	63%
CARDIAC	17	28%	6	40%	10	24%	6	25%
HEARING	10	16%	2	13%	7	17%	5	21%
MUSCULOSKELETAL	10	16%	1	7%	9	22%	7	29%
ENDOCRINE	7	11%	1	7%	5	12%	4	17%

Discussion

The most common new onset or worsening physical symptoms reported to the EHP nurse practitioner include respiratory (upper and lower), constitutional, neurological, gastrointestinal, eye and dermatological (skin).

The development of respiratory, eye, and skin symptoms is consistent with the recognized irritant properties of many of the acknowledged UNGD air emissions described in the earlier chart and also consistent with the symptoms reported in the published studies discussed previously.

Although the recognized air contaminants may be the primary exposure source for irritant symptoms, it is noteworthy that individuals using well water were more likely to experience respiratory, eye and skin symptoms than individuals on public water systems. If water contaminants have irritant properties, individuals may be affected during showering or other indoor water use through direct contact with the skin or eyes, or through inhalation, if the contaminants volatilize from the water.

The development of new onset or worsening respiratory symptoms is of particular concern given the potential for UNGD activities to exacerbate asthma, as already documented in the Rasmussen article (28), or to contribute to the development of asthma or the development or exacerbation of other respiratory conditions.

Sleep disruption and fatigue were the most common constitutional symptoms reported to the EHP nurse practitioner. Sleep disruption has many potential contributors with the most obvious potential UNGD contributors being noise and stress. Likewise, fatigue has many potential contributors, including sleep disruption, stress, and the potential neurological effects of some of the VOC's discussed previously. High levels of fatigue have been noted in prior published studies, most recently in the article by Tustin et al (29). There was minimal association between water source and constitutional symptoms.

The most common new onset neurological symptom reported was headaches, which can result from irritant exposures, but also from other neurological effects of VOC emissions or from exposure to low levels of carbon monoxide. New onset or worsening headaches have also been described in other published studies, most recently in the Tustin et al article (29) discussed above. VOC's are also recognized to contribute to the development of dizziness and memory problems. Again, individuals using well water were more likely to experience new onset neurological symptoms, suggesting that air emissions may not be the only exposure source contributing to the development of neurological symptoms.

Nausea and abdominal pain, which often have different etiologies, were the most common new onset gastrointestinal symptoms reported. Although nausea is a recognized potential health symptom from inhalation exposure to diesel exhaust or hydrogen sulfide, air exposures are less likely to contribute to abdominal pain. Of the 27 individuals reporting gastrointestinal symptoms, 22 were on private wells, suggesting a potential water contaminant contributing to their symptoms, a more likely explanation for the onset of abdominal pain.

In addition to physical symptoms, psychological symptoms, including stress, anxiety, irritability, moodiness and worry were frequently reported. The many contributors of UNGD activities to the development of these important symptoms have been examined elsewhere, and are beyond the scope of this discussion. It is interesting to note that there was no association between the use of private well water and the development of psychological symptoms, consistent with the likelihood that the development of these symptoms is not primarily a physiological response to the environmental contaminants generated by UNGD.

In summary, the new onset or worsening health symptoms that were most commonly reported to the EHP nurse practitioner in association with UNGD activity are generally consistent both with the recognized potential short term health effects of documented air emissions from UNGD activity and with symptoms reported in several published studies addressing UNGD health effects. Although the nature of likely water contaminants is not as well understood as air contaminants, having access to information on household water sources, the EHP review demonstrated that individuals on private wells had higher levels of health symptoms than those on public water. The increased prevalence of symptoms with well water use was most prominent for eye, skin, neurological and gastrointestinal symptoms, suggesting that water contamination may play a role in the development of these symptoms.

Although the EHP findings are limited by being based on self-reported symptoms from individuals who sought out EHP due to their concerns regarding UNGD, the review also has several strengths, some of which may be unique to this review:

- Proximity to UNGD sources - Prior to the review of the cases, the proximity and timing of potential UNGD activities had been established. In reviewing the then de-identified cases, only individuals who had been documented to be within 1 km of a UNGD activity at the time of their assessment were included in the review.
- Timing of onset of symptoms - The reviewers had access to the timing of onset of symptoms in relationship to the timing of onset of potential UNGD exposures. Only symptoms which worsened or occurred after the onset of potential UNGD activity were included in the symptom tally.
- Knowledge of medical history and other exposure sources – The reviewers had access to extensive medical histories and to information on other potential exposure sources. Symptoms that were as likely explained by unrelated medical conditions or to exposures unrelated to UNGD, were also not included in the symptom tally. The exclusion of symptoms less likely to be related to UNGD activity, strengthens the association with UNGD activity of those symptoms retained.
- Identification of household water source – The reviewers had access to information on household water source, allowing a determination of the relative prevalence of symptoms of individuals relying, at least in part, on well water, versus those on public water systems.

Conclusions

This review of EHP cases adds to the expanding body of evidence that UNGD activity is adversely affecting the health of individuals living in proximity to this activity. The potential health effects of the recognized UNGD air emissions are well documented historically. The most common new onset symptoms of individuals living in proximity to UNGD activities are, for the most part, predictable based on what is known regarding exposure to these air contaminants.

The observation that individuals using well water have more symptoms than those on public water suggests that water contaminants may also be contributing to the onset of symptoms. In particular, the observation that individuals using well water were much more likely to experience new onset gastrointestinal symptoms, including abdominal pain, than those on public water, provides a potential explanation for the onset of symptoms less easily attributable to air contaminants.

In conclusion, the EHP results should augment concern regarding the adverse health impacts of UNGD activities, and, in addition, underscore the need for a greater understanding of potential water contamination.

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Works Cited

1. *Health effects of outdoor air pollution.* **Abelsohn, A and Stieb, DM.** August 2011, Canadian Family Physician, Vol. 57, pp. 881-887.
2. **PADEP.** Air Emissions Data from Natural Gas Operations. *Pennsylvania Department of Environmental Protection.* [Online] [Cited: July 25, 2016.] <http://www.dep.pa.gov/Business/Air/BAQ/BusinessTopics/Emission/Pages/Marcellus-Inventory.aspx>.
3. **ATSDR.** Toxic Substances Portal - Benzene. *ATSDR Agency for Toxic Substances & Disease Registry.* [Online] August 30, 2016. <http://www.atsdr.cdc.gov/toxfaqs/tf.asp?id=38&tid=14>.
4. —. Toxic Substances Portal - Ethylbenzene. *ATSDR Agency for Toxic Substances and Disease Registry.* [Online] August 30, 2016. <https://www.atsdr.cdc.gov/substances/toxsubstance.asp?toxid=66>.
5. —. Toxic Substances Portal - Toluene. *ATSDR Agency for Toxic Substances & Disease Registry.* [Online] [Cited: August 30, 2016.] <http://www.atsdr.cdc.gov/substances/toxsubstance.asp?toxid=29>.
6. **CCOHS.** OSH Answers Fact Sheets. *CCOHS Canadian Centre for Occupational Health and Safety.* [Online] August 30, 2016. http://www.ccohs.ca/oshanswers/chemicals/chem_profiles/xylene.html.
7. **ATSDR.** Toxic Substances Portal - Methylene Chloride. *ATSDR Agency for Toxic Substances & Disease Registry.* [Online] August 30, 2016. <http://www.atsdr.cdc.gov/substances/toxsubstance.asp?toxid=42>.
8. —. Toxic Substances Portal - Formaldehyde. *ATSDR Agency for Toxic Substances & Disease Registry.* [Online] [Cited: August 30, 2016.] <https://www.atsdr.cdc.gov/substances/toxsubstance.asp?toxid=39>.
9. **OSHA.** Diesel Exhaust. *Occupational Safety and Health Administration.* [Online] [Cited: August 30, 2016.] <https://www.osha.gov/SLTC/dieselexhaust/>.
10. **ATSDR.** Toxic Substances Portal - Hydrogen Sulfide. *ATSDR Agency for Toxic Substances & Disease Registry.* [Online] [Cited: August 30, 2016.] <http://www.atsdr.cdc.gov/substances/toxsubstance.asp?toxid=67>.
11. *A review of airborne polycyclic aromatic hydrocarbons (PAHs) and their human health effects.* **Kim, Ki-Hyun, et al., et al.** 2013, Environment International, Vol. 60, pp. 71-80.
12. *Prenatal Airborne Polycyclic Aromatic Hydrocarbon Exposure and Child IQ at Age 5 Years.* **Perera, Frederica P, et al., et al.** 2, August 2009, Pediatrics, Vol. 124.
13. **EPA.** Particulate Matter (PM) Pollution. *EPA US Environmental Protection Agency.* [Online] [Cited: August 30, 2016.] <https://www.epa.gov/pm-pollution/health-and-environmental-effects-particulate-matter-pm>.
14. **EPA .** Ozone Pollution. *EPA - Environmental Protection Agency.* [Online] [Cited: August 30, 2016.] <https://www.epa.gov/ozone-pollution/health-effects-ozone-pollution>.
15. **EPA.** Radon. *EPA - Environmental Protection Agency.* [Online] [Cited: August 30, 2016.] <https://www.epa.gov/radon/health-risk-radon>.
16. **Levy, Barry S and Wegman, David H.** *Occupational and Environmental Health, Recognizing and Preventing Disease and Injury.* New York : Oxford University Press, 2011.
17. **EPA.** Nitrogen Dioxide. *EPA US Environmental Protection Agency.* [Online] [Cited: August 30, 2016.] <http://www.epa.gov/oaqps001/nitrogenoxides/health.html>.
18. —. Ground Water and Drinking Water, National Primary Drinking Water Regulation Table. *EPA US Environmental Protection Agency.* [Online] <https://www.epa.gov/ground-water-and-drinking-water/national-primary-drinking-water-regulation-table>.

19. **PADEP.** Oil and Gas Reports. *Pennsylvania Department of Environmental Protection*. [Online] [Cited: September 11, 2016.] <http://www.dep.pa.gov/DataandTools/Reports/Oil%20and%20Gas%20Reports/Pages/default.aspx>.
20. **EPA.** EPA's Study of Hydraulic Fracturing and Its Potential Impact on Drinking Water Resources. *EPA - US Environmental Protection Agency*. [Online] [Cited: September 11, 2016.] <https://www.epa.gov/hfstudy/overview-epas-draft-assessment-potential-impacts-hydraulic-fracturing-oil-and-gas-drinking>.
21. **Coleman, Dennis and Coleman, Todd.** Collecting Water Samples for the Determination of Dissolved Gas Concentrations. *Isotech*. [Online] [Cited: August 30, 2016.] http://www.gwpc.org/sites/default/files/event-sessions/Coleman_DennisFinal.pdf.
22. **NYSDEC.** Revised Draft Supplemental Generic Environmental Impact Statement. *New York State Department of Environmental Conservation*. [Online] 2011. [Cited: September 19, 2016.] <http://www.dec.ny.gov/data/dmn/rdsgeisfull0911.pdf>.
23. *Auditory and non-auditory effects of noise on health.* **Basner, Mathias, et al., et al.** 2014, *Lancet*, pp. 1325-1332.
24. *Human health risk assessment of air emissions from development of unconventional natural gas resources.* **McKenzie, LM, et al., et al.** 2012, *Sci Total Environ*, Vol. 424, pp. 79-87.
25. *Impacts of gas drilling on human and animal health.* **Bamberger, M and Oswald, RE.** 2012, *New Solut*, Vol. 22, pp. 51-71.
26. *Assessment and longitudinal analysis of health impacts and stressors perceived to result from unconventional shale gas development in the Marcellus Shale region.* **Ferrar, KJ, et al., et al.** 2013, *Int J Occup Environ Health*, Vol. 19, pp. 104-112.
27. *Investigating links between shale gas development and health impacts through a community survey project in Pennsylvania.* **Steinzor, N, Subra, W and Sumi, L.** 2013, *New Solut*, Vol. 23, pp. 55-83.
28. *Proximity to Natural Gas Wells and Reported Health Status: Results of a Household Survey in Washington County, Pennsylvania.* **Rabinowitz, PM, et al., et al.** 1, January 2015, *Environ Health Perspect*, Vol. 123, pp. 21-26.
29. *Association between unconventional natural gas development in the Marcellus Shale and asthma exacerbations.* **Rasmussen, SG, et al., et al.** July 2016, *JAMA Intern Med*.
30. *Associations between Unconventional Natural Gas Development and Nasal and Sinus, Migraine Headache, and Fatigue Symptoms in Pennsylvania .* **Tustin, Aaron W, et al., et al.** August 2016, *Environmental Health Perspectives*, pp. 1-34.
31. **FracTracker.** FracTracker. *FracTracker*. [Online] 2015. <https://www.fractracker.org/>.