New York - Environmental Health Monitoring Project

EHP ENVIRONMENTAL HEALTH PROJECT SOUTHWEST PENNSYLVANIA

Safety Assessment of Siting Large Shale Gas Compressor Stations in Residential Neighborhoods in New York State

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Director's note

Now in its fourth year, the New York Environmental Health Monitoring Project (NY Project), a program of the Southwest Pennsylvania Environmental Health Project (EHP), has reached several important milestones serving communities facing shale gas compressor station development. EHP has developed tools to assess the health and air quality impacts affecting local residents, engaged residents in the use of these tools, and interpreted results to identify personal and community actions to protect health.

Through our community partnerships, our air screening models, and recent research into New York's compressor station emissions, EHP has determined that there are direct and indirect health impacts associated with chemical emissions from these industrial sites. High exposures could occur 10% of the time within 0.5 km (0.3 miles) of low-emitting stations and within 3.0 km (1.9 miles) of high emitting stations. Such exposures are long enough to result in acute health symptoms. We consider this an emerging health problem for New York State communities; a problem that requires ongoing surveillance of air exposures and health impacts. [1]

This report shows how EHP's tools have been used to assess potential health impacts related to the ongoing expansion of shale gas pipeline infrastructure. One of the most important lessons learned by participants is that local weather patterns play a large role in exposures to outdoor pollutants, for homes, neighborhoods, schools and other community spaces. Monitoring continuously for particulate matter ($PM_{2.5}$), sampling for volatile organic compounds (VOCs) and air modeling to estimate levels of impact based on weather and distance, combine to clearly show how weather affects local exposure, causing repeated periods of high exposures about 10% of the time. Acute health symptoms may result from these exposures. EHP's comprehensive protocol provides communities with:

1. Detailed evidence of baseline and peak exposures to pollutants based on levels of continuous monitoring and concurrent weather data.
2. A tool that shows clear evidence of the direction from which the highest pollutant levels come.
3. Estimated levels of air pollution at different distances from a fully operating compressor station based on an air screening model.
4. The level of health risk associated with exposure at certain distances from the source for a set of known shale gas pollutants, and health symptoms likely to be experienced.
5. Recommendations on how best to protect individual and community health.

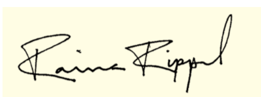
Current national and state regulations do not provide adequate protection for human health impacts near many of these industrial sites. The federal government removed many health and environmental safeguards from the shale gas and oil development industry when it passed the Energy Policy Act of 2005. That Act, and a series of additional exemptions, removed much of

[1] More detailed information on New York compressor station emissions and health impacts are found in the companion report, "Potential Health Effects Associated with Chemical Emissions from the Production, Transportation and Use of Natural Gas, CNG and LPG in New York: 2014". October 2017. https://www.environmentalhealthproject.org/resources

the EPA's responsibility for protecting the environment and human health from contaminants resulting from the shale gas development, including pipelines and compressor stations, now occurring in New York. The exemptions, taken together, have the dual effect of making potential exposures more likely while making their disclosure less likely. EHP, as a nonprofit public health organization, works with communities to assess health impacts from shale gas development to address this large and growing gap in public health protection.

EHP is thankful to the Park Foundation for its support. We are also especially grateful to the residents in each of the communities we worked with – for their effort and dedication and for sharing their experience, knowledge, and insights about living close to pipelines and compressor stations.

In Good Health,



Raina Rippel, Director, EHP

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Executive Summary

Community health concerns are the driving force of the New York Environmental Health Monitoring Project's investigation concerning the current and potential build-out of shale gas transport; and community effort has been key to its success. The request for assistance from nine communities across the state shows that the scope of this problem is broad. Based on our collaborative investigation, the Southwest Pennsylvania Environmental Health Project has identified an emerging public health problem that requires continued action by residents and public health experts to ensure the protection of individual and community health in New York State.

"How close is too close?"
Based on this question posed to us by New York residents, EHP responded to communities with both proposed compressor station sites and existing sites proposed for expansion. In partnership with local volunteers, we assessed air exposures at residences and surveyed community health, focusing on the following questions:

Exposures. What does exposure currently look like in these communities?
- What is the current mixture of pollutants?
- What is the intensity of air exposures?
- Will this exposure change with further development?

Health Impacts. What are the health consequences of living near shale gas compressor stations?
- What is the current health status in these communities?
- How might this change with further development?
- How should public health be protected, now and in the future?

Results of the Investigation
Tools that measure the intensity of air exposures and that monitor health status were developed early on and remain in place. These include continuous monitoring of fine particulate matter, sampling for volatile organic compounds, modeling potential exposures from fully operating compressors, and surveying specific health parameters among local residents. Key factors in the exposure assessment are the specific chemical mixtures posing health risk and local weather patterns that drive residential exposures. Linking these factors allows us to determine the patterns of intense, episodic exposures that can cause acute health effects.

Air Exposure
The chemical mixture of concern includes nitrogen oxides (NO_x), carbon monoxide (CO), VOCs, formaldehyde and $PM_{2.5}$. These are the top five chemicals, after methane and carbon dioxide, emitted from New York compressor stations, based on data from the National Emissions Inventory and from the Pennsylvania shale oil and gas inventory.

Basic weather patterns in the northeastern US include times of low air diffusion about 10% of the time. These are the times most likely to cause intense airborne chemical exposures near fully operating compressor stations. Based on the application of EHP's Air Model, we find that:

For large, Title V compressor stations emitting approximately 55 tons/year, high exposures could occur out to a distance of 3 kilometers (1.9 miles) 10% of the time. For smaller compressor stations high exposures could occur 10% of the time at distances between 0.5-1 kilometer (0.3-0.6 miles), depending on emission levels. Low and moderate exposures would occur more often and at greater distances.

Health Impact

The health status of the New York communities EHP surveyed was generally good. We compared New York community health status to that of Pennsylvania residents with known exposures to shale gas emissions. In Pennsylvania, these residents frequently experience a set of health symptoms that strongly suggest exposure to a specific set of chemical emissions found in shale gas. Surveillance of New York residents' air quality and exposures for those living near compressor stations is needed, to assure that shale gas activities are not impacting communities near these industrial sites.

The chemicals of concern (NO_x, CO, VOCs, formaldehyde and $PM_{2.5}$) are known to affect several body systems. These are the respiratory, neurological and cardiovascular systems as well as the ears, eyes, nose and throat system. The health effects that could be experienced by these exposures include:

- Eye, nose, throat irritation
- Headache
- Shortness of breath
- Palpitations
- Chest pain
- Changes in blood pressure and/or heart rate
- Impaired cognitive function such as confusion and difficulty concentrating

Chronic health impacts, while not immediately observable, are also a concern.

Not all residents would experience symptoms. Some may experience only one or two, while residents with ongoing health problems are most likely to be acutely affected. Outreach to the New York medical community is highly recommended to promote awareness of health parameters that may indicate acute exposure to shale gas emissions.

Conclusions

In New York State, if gas pipelines continue to expand, continuous air monitoring and health assessment is necessary to identify impacts and intervene to protect the public from environmental health impacts. The components of shale gas emissions are putting an increased toxic burden on the exposed population and the significance of these chemical mixtures is not yet fully known. What is known is that some residents living in areas of shale gas development show acute health symptoms and peer reviewed literature points to long-term health impacts.

EHP recommends vigilant, long-term surveillance of air exposures and community health.

Specific recommendations for communities include:

- Continuous monitoring of chemical components of emissions such as particulate matter and volatile organic compounds.
- Concise health surveys conducted every six months. EHP recommends the nationally validated SF-36 survey and a targeted set of questions specific to shale gas exposure.
- Community Health Impact Assessments conducted by town officials. This type of assessment provides residents with a full disclosure of what is known, or not known, about health impacts related to compressor station emissions.
- Registration of residents in a Shale Gas Health Registry.
- Community effort to develop and enforce health-based regulations on local industrial development.

Introduction

The shale gas industry's plan to expand shale gas transport pipelines, add new compressor stations and expand old ones has caused concern in communities throughout New York State. The New York Environmental Health Monitoring Project (NY Project) was established in response to community members' fears that emissions from compressor stations operating near their homes could affect their health. These concerns arose when residents experienced episodic health symptoms, including sore throats and burning eyes, which were sometimes associated with odors from nearby compressor stations. Communities facing impending compressor station development also became concerned about future risks. They wanted to know, "how close is too close?" EHP's response has been to apply a systematic approach to providing site-specific environmental assessment and guidance for communities facing compressor station construction or build-out.

The Southwest Pennsylvania Environmental Health Project (EHP) has worked with nine New York communities in the past four years. Of the nine sites, four had completed compressor station expansions by fall 2017. Two of these sites have new compressor stations and two have recently expanded compressor stations. Two additional sites will have completed site developments by early 2019. The remaining three projects have been delayed or have withdrawn permit applications.

A note about the context for the assessment. Initially, two phases of the project were planned for each site; phase 1 involved a *pre*-construction air and health assessment and phase 2 involved *post*-construction air and health assessment. During phase 2, in the four communities where compressor station construction/expansion was complete, it became apparent that the stations were not yet functioning to capacity when post-construction monitoring took place.

It is not known what level of gas transport occurred during that time, but residents in each community noted very little activity onsite. These facilities were built in anticipation of a much larger regional and global export shale gas market and we believe emissions and the potential for health effects will be much greater in the future. The pre- and post- construction measurements of exposures and health results are, therefore, descriptive of the very early stages of industry expansion in New York State. To address the likelihood of pipelines running at full capacity in the future, EHP has prepared an air model assessment and highly recommends continuous air and health monitoring for several years, allowing communities to track changes in exposures as gas transport increases (see Recommendations Section).

The research on shale gas development, its air and water contaminants and its potential link to acute, chronic and developmental health conditions, has grown dramatically over the last five years. Documenting and understanding exposures and health at the community level enhances, and is enhanced by, existing research on the national shale gas and oil industries.

Rationale for Community Monitoring

The development of EHP's New York project protocols stemmed from our work in Pennsylvania, where we have been actively assisting individuals and communities experiencing impacts from unconventional gas development (UGD) for the past six years. At the invitation of community members in 2014, EHP conducted a pilot project in Minisink, NY around a newly built shale gas compressor station.[2] Based on these community results and emerging published research, we determined that health impacts from shale gas compressor stations were not only plausible, but also likely.

But why would health risks be greater now than in the past? The components in shale gas pipelines have changed due to recent developments in hydrofracturing techniques. The shale gas now contains more toxic chemicals, including the carcinogen radium. The US EPA National Emissions Inventory (NEI) lists 70 chemicals emitted from gas compressor stations in New York State.[3]

Operating compressor stations emit continuously, at baseline levels, and also in episodic, high level, short-term peaks. Peaks in exposures can cause both acute and chronic health effects in nearby residents. Local weather inversions and times of low wind speed can exacerbate exposures and health impacts. Analyses of the short-term and long-term variability in emissions are critical to understanding potential health impacts for residents living within a few miles of these industrial pollution sources.

Therefore, the goal of this project is to evaluate the potential impacts to residents living near New York's expanding shale gas pipelines and compressor stations. We assess both current and potential future exposures to compressor station emissions and concurrently evaluate the health status of individuals within the communities for baseline health assessments. To do this we:

1. Estimate the potential exposures that would occur at each residence when the build-outs are complete and compressors operate full time.
2. Measure the actual exposures inside and outside nearby homes to determine the range of concentrations of the gas emissions that could be inhaled.
3. Determine the weather conditions that enhance exposures to each home and identify periods when the risks of exposures are highest.
4. Determine the current overall health status of members of the communities using a nationally accepted health screening tool and an EHP health survey tool.
5. Determine, through health surveys, the presence of health effects known to be associated with exposures to shale gas derived from "fracked" shale gas.

Because hourly weather changes influence exposures, and the chemical contents of air pollution affect health, our methods include a minimum of one month of continuous 1-minute air sampling for particulate matter ($PM_{2.5}$) and 12 or 24-hour VOC sampling. Environmental exposures can

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[2] EHP Summary of Minisink Monitoring Results. Released March 2015. https://www.environmentalhealthproject.org/sites/default/files/assets/resources/summary-of-minisink-results.public.pdf

[3] EHP Technical Report: P.N. Russo and D. O. Carpenter, Potential Health Effects Associated with Chemical Emissions from the Production, Transportation and Use of Natural Gas, CNG and LPG in New York: 2008-2014. p.3. Released October 2017.

then be linked with completed health assessment forms for all members of each household, including a home environment assessment and a health and well-being survey (also known as the SF-36). In sum, EHP's approach provides a comprehensive characterization of risk.

For information on site selection and pipeline description see Appendix 1.
For information on project methods and data analysis see Appendix 2.
For information on EHP's Health Risk Guidance document see Appendix 3.

Exposure Assessment Tools and Outcomes

Each component of EHP's community air exposure assessment is described here, and overall results for each are shared. The modeled estimates of expected chemical exposures near New York State compressor stations address impacts from fully operating sites. The projected levels of chemical exposure from EHP's air model are paired with EHP's health risk guidance table, to estimate the potential for public health impacts near compressor stations. During the monitoring periods for $PM_{2.5}$ and for VOCs, none of the pipelines moving gas through the communities were running at the capacity the industry has projected for the expanded transport lines. The data collected is essentially background data. Results shared here are based on our work to date with the nine communities participating in the project.

First we present results from EHP's air screening model, showing *estimated exposures from fully operating sites*, and answering the question of "how close is too close?" Next, we present results to date from residential, outdoor, $PM_{2.5}$ continuous monitoring in all communities. This is followed by a summary of VOC air sampling results, followed by a review of EHP's PM Impact App, which shows residents information on the direction of greatest impact for $PM_{2.5}$ air pollutants at their homes. In the discussion section on exposures, we show how these components are integrated to provide a comprehensive community assessment.

Estimating potential exposures: The EHP Air Model

The EHP Air Model provides estimates of exposure levels within a radius of 0.5km - 10km from a compressor station. It brings together the three factors of emissions, distance, and local weather that affect community exposures. This analysis compliments the air monitoring for VOCs and $PM_{2.5}$ conducted by residents participating in the project and can be generalized to the entire community.

Two categories of compressor stations, based on emission levels and New York air pollution permits, are covered in this project. “Title V” permitted stations are considered major air pollution sources. “Air State Facility” (ASF) permitted stations generate between 50-99% of the lowest thresholds for Title V sites.

Table 1 shows four categories of exposure estimates for large ASF permitted compressor stations. These range from extreme to low, for distances from the compressor station fenceline out to 10 kilometers (6.2 miles).

Table 2 shows the estimated exposure categories for the smallest ASF permitted compressor stations. Based on this generic categorization, all ASF compressor stations would fall within these boundaries. The air models’ numerical results are found in Appendix 2, Tables A and B.

Estimation of exposures from non-Title V compressor stations in New York

To illustrate the range of estimated exposure levels for communities located near ASF permitted compressor stations, we used the EHP Air Model for one of the smallest Title V sites as an upper-bound limit of air emissions, and ½ of these emission levels for a lower-bound limit. ASF permitted sites, by definition, emit 50 – 99% of Title V thresholds. For this analysis we chose the smallest Title V compressor station, in terms of average yearly emissions, listed in the New York National Emissions Inventory (NEI).[1]

The New York Title V compressor station with the lowest reported emissions in the NEI shows average annual emissions of 1588 grams/hour (15.3 tons/year) for the top five contaminants after methane and carbon dioxide: NOX, CO, VOCs, Formaldehyde, and PM.[1] We consider the air model’s estimated exposures to be close to the upper limit of ASF permit levels (i.e. larger ASF stations would approach these levels).

Annual median levels and 90th percentile levels provide average and peak exposure information. Peaks occur about 10% of the year, but it should be noted that not all residents would experience all peaks because some homes will not be downwind from the compressor station on any given day. Table 3 shows the health effects associated with these exposure levels.

Table 1. Estimated upper boundary of exposure levels for large Air State Facility permitted compressor stations, emitting approximately 15.3 tons/year of the mixture (NO_x, CO, VOCs, Formaldehyde, PM).

Distance from compressor	0.1 km fenceline	0.5 km	1 km	2 km	3 km	5 km	10 km
Annual median level	Extreme*	Moderate	Low	Low	Low	Low	Low
Annual peak levels 10% of time	Extreme	Extreme	High	Moderate	Low	Low	Low

** See Table 3 for category definitions*

Table 2. Lower limit exposure levels for small Air State Facility permitted compressor stations, emitting approximately 7.6 tons/year of the mixture (NO_x, CO, VOCs, Formaldehyde, PM).

Distance from compressor	0.1 km fenceline	0.5 km	1 km	2 km	3 km	5 km	10 km
Annual median level	High*	Low	Low	Low	Low	Low	Low
Annual peak levels 10% of time	Extreme	High	Moderate	Low	Low	Low	Low

** See Table 3 for category definitions*

Connecting Exposure Levels to Health Risk Analysis

The health impacts associated with the air model's estimated exposures are found in EHP's Risk Guidance table (Table 3). The Risk Guidance table defines the estimated air levels at which the toxic actions would occur. EHP's health guidance is based on workplace safety guidance and identifies the possible symptoms experienced when exposed to the mixture of chemicals.[4]

Table 3. Exposure levels of the mixture (NO_x, CO, VOCs, Formaldehyde, PM) emitted from natural gas compressor stations that can elicit health symptoms. Levels reported in ($\mu g/m^3$)[5].

Exposure	Air level	Possible symptoms experienced	Physical system affected
Low	less than 500 $\mu g/m^3$	Eye and throat irritation	Ears, eyes, nose and throat
Moderate	500 to 1000 $\mu g/m^3$	Eye and throat irritation, headache	Ears, eyes, nose and throat; neurological
High	1000 to 2500 $\mu g/m^3$	Eye and throat irritation, headache, shortness of breath, palpitations, chest pain, changes in blood pressure and/or heart rate	Ears, eyes, nose and throat; neurological, respiratory, cardiovascular
Extreme	2500 to 5000 $\mu g/m^3$ and above	Eye nose, throat irritation, headache, shortness of breath, palpitations, chest pain, changes in blood pressure and/or heart rate, impaired cognitive function such as confusion and difficulty concentrating	Ears, eyes, nose and throat; neurological, respiratory, and worsening cardiovascular effects

[4] Toxicology references: NIOSH Pocket Guide to Chemical Hazards. U.S. Department of Health and Human Services, Center For Disease Control. 1990; Handbook of Poisoning, R.H. Dreisbach and W.O. Robertson. 1987.
[5] See EHP Risk Guidance report in Appendix 3 for Guidance rationale.

One compressor station in this project, the Borger station in Dryden, NY, has a Title V permit. This station has emitted an annual average of 55 tons/year, before the recent expansion in 2017.[6] Table 4 shows estimated air exposure levels between 0.1 and 10km.

Table 4. Air exposure levels for the Borger Title V compressor station (pre-expansion), emitting an estimated 55 tons/year of the mixture (NO_x, CO, VOCs, Formaldehyde, PM).

Distance from compressor	0.1 km fenceline	0.5 km	1 km	2 km	3 km	5 km	10 km
Annual median level	Extreme*	High	Low	Low	Low	Low	Low
Annual peak levels 10% of time	Extreme	Extreme	Extreme	High	High	Moderate	Low

** See Table 3 for category definitions*

Measuring Actual Exposures: PM2.5 continuous monitoring
In order to validate the air model we measured particulate matter ($PM_{2.5}$), one of the top pollutants. To characterize actual exposures, we installed Speck Sensors, which are continuous monitoring devices, inside and outside residences. [7] The Speck samples the air every minute, specifically measuring the presence of $PM_{2.5}$, which are particles that have a diameter of less than 2.5 micrometers (about 30 times smaller than a human hair). To establish typical patterns of weather variability and its impact on $PM_{2.5}$ exposures, EHP's protocol includes 32 days of continuous, 1-minute sampling of $PM_{2.5}$ inside and outside residences within 2km (1.25 miles) of a compressor station site.

The Speck Index is an analytic approach developed by EHP. To show the patterns of exposure affecting residents near their homes, the index identifies three key factors in determining health impacts:

1. how much air pollution reaches the home,
2. how frequently peak exposures occur, and
3. how long the peak exposures last.

The Speck Index produces five statistics from the analysis of 32 days of 1-minute data. Table 5 shows the range of component results from outdoor monitoring at the four sites along the New Market pipeline project.

[6] EHP Technical Report: P.N. Russo and D. O. Carpenter, Potential Health Effects Associated with Chemical Emissions from the Production, Transportation and Use of Natural Gas, CNG and LPG in New York: 2008-2014. p.92. Released October 2017.
[7] The Speck is a low cost monitor which allows EHP to carry out detailed analysis of short and long term exposure.

Table 5. Speck Index outdoor exposure results from four communities along the Dominion New Market pipeline.

Component	Range of results	Average[8]
Baseline	2.0 – 27.4 µg/m^3	9.0 µg/m^3
Number of peaks per day	O.8 - 4.2	2.8
Duration of peaks	18 -47 minutes	24 minutes
Time between peaks	6 – 29 hours	8.4 hours
Total sum of particle counts*	1.9 – 23.0 mg/m^3/day	4.5 mg/m^3/day

** This shows the daily accumulation of particles. The average of 4.5 mg/m3/day equals 4500 µg /m3/day.*

These results provide a background assessment of $PM_{2.5}$ exposures before the new and expanded compressor stations are in full operation. Follow-up monitoring is needed to evaluate exposures during full operation.

Why is continued monitoring needed to evaluate health risk?

- Peak exposures will likely be more intense when pipelines are fully operating, and may cause more poor air quality days.
- When pipeline compressors are fully operating, additional peaks can occur due to gas venting, blowdowns and accidental releases.
- Higher baseline values, frequent peaks, and longer peaks would increase exposure to PM and other chemicals, increasing the risk of health impacts.
- Peak exposures are not addressed in current Federal regulations. The National Ambient Air Quality Standards (NAAQS) provide regional baseline air quality data but do not address short term peaks which can cause acute health effects. Continuous monitoring and the Speck Index provide more specific health-related information.

Measuring Actual Exposures: Volatile Organic Compound Sampling

We know from monitoring $PM_{2.5}$ that air pollutants are present in the vicinity of compressor stations. We also know that compressor stations emit a large mixture of chemicals, based on industry reports to the NEI. What else is found in the air with $PM_{2.5}$?

VOC sampling provides qualitative data on types of chemical exposures that may be occurring along with $PM_{2.5}$. A mixture of chemicals is more concerning than a single chemical pollutant in terms of health impact. In addition, a mixture that includes PM is especially concerning, because when individuals inhale PM it can carry other chemicals into the deep lungs, increasing the potential for health impacts.

In the NY Project, residents employed summa canisters, formaldehyde badges and hydrogen sulfide badges (which can be attached to canisters) to collect 12 or 24-hour air samples. They sampled during the best weather conditions for catching locally emitted VOCs – overnight and during times of low wind speed.

[8] Average of all Speck Index results in EHP database.

Summary of VOC results
All VOC summa canister samples returned chemical detections, ranging from 1 to 15 in number of chemicals per sample. All chemicals detected were below the level of health concern for each individual chemical, but for health evaluations, the impact of multiple low level detections should not be dismissed.

Tables 6a-6c show the results of pre- and post- construction sampling for three of the four New Market project sites. The Madison County site used different sampling protocols and those results are not included here. As noted earlier, while these are the first four locations to complete pre- and post- construction monitoring, it was reported by community members that during sampling the stations were not fully operating. This may explain why, at the two sites where expansion and upgrades were made, post-construction results show fewer detections than pre-construction. The Chemung County site, where a new compressor has been built, shows five post-construction detections where four had previously been detected.

The following three tables show VOC sampling results near compressor stations located in three counties along the Dominion Pipeline New Market project.

Table 6a. Shows results from one pre-expansion sample during operation, and 2 post-expansion samples during no or low operation status.

Montgomery County, Brookmans Corners (existing, then expanded)			
Chemical	**μg/m^3**	**μg/m^3**	**μg/m^3**
	Pre-expansion operating	**Post-expansion No or low operation**	**Post-expansion No or low operation**
Acetone	19	7.6	5.96
Dichlorodifluoromethane	1.9	ND	ND
Naphthalene	0.76	ND	ND
Propene	0.79	ND	ND
Toluene	0.83	6.33	ND
Trichlorofluoromethane	1.0	ND	ND
1,3,5-Trimethylbenzene	0.89	ND	ND
Vinyl Acetate	6.8	ND	ND

ND = not detected

Table 6b. Shows results from two pre-expansion samples during operation, and 2 post-expansion samples during no or low operation status.

Tompkins County, Borger Station (existing, then expanded)				
Chemical	**µg/m³ Pre-expansion operating**	**µg/m³ Pre-expansion Operating**	**µg/m³ Post – expansion No or low operation**	**µg/m³ Post – expansion No or low operation**
Acetone	ND	ND	10.3	5.06
Benzene	3.3	6.4	ND	ND
Chloromethane	ND	ND	1.12	1.09
Dichlorodifluoromethane	2.2	2.6	ND	ND
Ethanol	11	17	ND	ND
Ethyl Acetate	ND	2.6	ND	ND
Ethylbenzene	1.8	3.7	ND	ND
4-Ethyltoluene	ND	0.92	ND	ND
n-Heptane	1.1	2	ND	ND
Hexane	ND	ND	23.1	ND
n-Hexane	4.2	9.9	ND	ND
Methylene chloride	ND	ND	34.2	ND
alpha-Pinene	ND	1.2	ND	ND
Propene	1.1	2.4	ND	ND
Toluene	12	26	ND	2
Trichlorofluoromethane	1.1	1.3	ND	ND
1,2,4-Trimethylbenzene	1.9	3.2	ND	ND
m,p-xylenes	7.4	14	ND	ND
o-xylene	2.8	5.5	ND	ND

ND= not detected

Table 6c. Shows results from one pre-construction sample and 2 post-construction sample during no or low operation status.

Chemung County, Horseheads (new construction)			
Chemical	**µg/m^3**	**µg/m^3**	**µg/m^3**
	Pre-conststruction No compressor	**Post-construction No or low operation**	**Post-construction No or low operation**
Acetone	ND	14.6	8.3
Chloromethane	ND	1.18	1.24
Dichlorodifluoromethane	2.3	2.52	2.72
Ethyl Acetate	3.3	ND	ND
Propene	2.1	ND	ND
Methylene chloride	ND	23.3	8.49
Trichlorofluoromethane	1.2	ND	ND
2-Propanol	ND	8.36	2.48

Hydrogen sulfide and formaldehyde were not detected at any sites. The method reporting limit on the samples taken may have been too high for detection of low amounts. Reporting limits were 0.57 µg/m^3 and 0.2 µg/m^3, respectively.

Based on the results from the air model, $PM_{2.5}$ monitoring and VOC sampling we know that specific chemicals found near compressor stations can affect the health of nearby residents. Table 7 shows which health systems are affected by the chemicals EHP has identified as most concerning in this project.

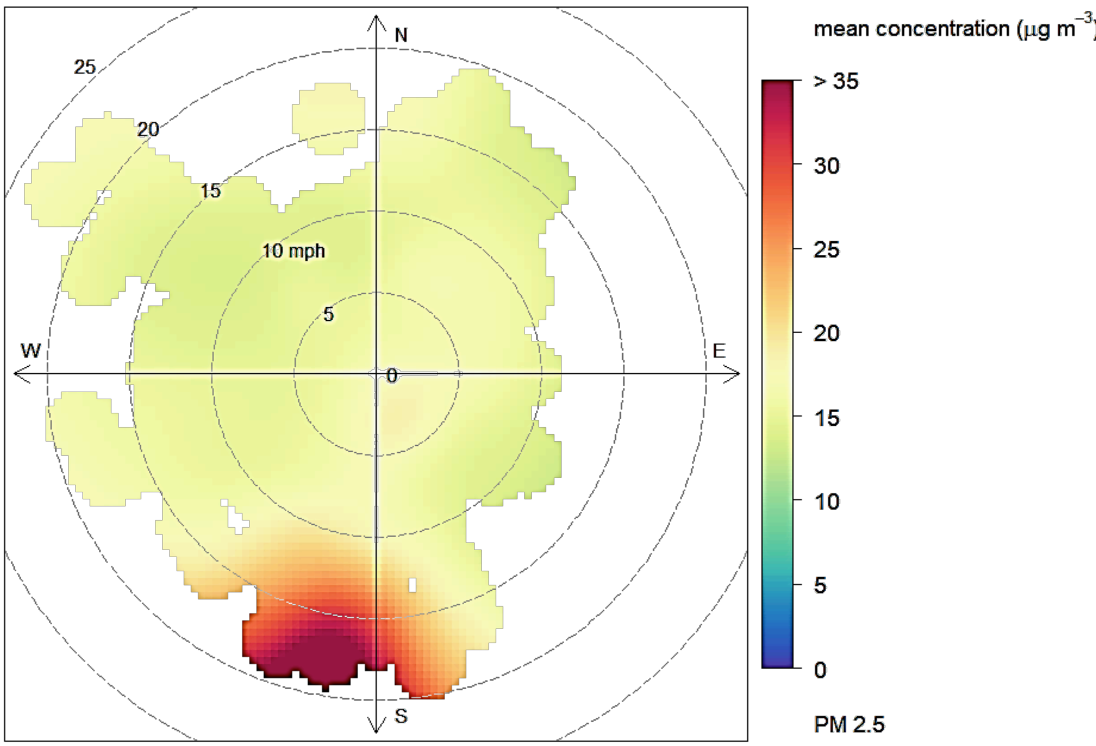
Table 7. Health systems affected by chemicals identified as of concern by EHP.
Sourced from EHP air sampling and emissions reported from the NEI for New York Compressor Stations.

Eyes, ears, nose and throat	**Respiratory System**	**Neurological System**	**Constitutional System**	**Cardiovascular System**
VOCs	VOCs	VOCs	VOCs	VOCs
Methylene Chloride*		Methylene Chloride	Methylene Chloride	
Formaldehyde*	Formaldehyde			
Halogenated Hydrocarbons*		Halogenated Hydrocarbons		
	$PM_{2.5}$			$PM_{2.5}$
NO_x	NO_x		NO_x	
			CO	CO

* *These chemicals are examples of classes of VOCs identified by VOC sampling or reported by the NEI.*

Determining how wind conditions enhance exposures: PM Impact App
The PM Impact App addresses two critical questions about exposures. It shows what weather conditions cause $PM_{2.5}$ levels to rise near a residence and it shows the direction from which chemical exposures come from. The PM Impact App, developed for EHP, merges local, time-synchronized, weather data from nearby airports with the continuous Speck $PM_{2.5}$ data. The resulting polar plot, as seen in Figure 1, shows residents the wind direction and wind speeds that bring $PM_{2.5}$ to their location.

Figure 1. Example of PM Impact App polar plot showing mean concentration in µg/m³



The image displays three important aspects of an outdoor Speck monitor's results: **the direction** from which $PM_{2.5}$ comes; **the intensity** of the $PM_{2.5}$ measurements; and **the wind conditions** at the times of exposure. In the image, the Speck monitor is located in the center where the lines cross. The endpoints of the lines represent the cardinal directions of North, South, East, and West with North at the top. The intensity of $PM_{2.5}$ levels is shown in the range of colors from blue (low exposure) to red (high exposure). The concentric circles represent the wind speed, with low wind speed near the center and higher wind speeds further out.

What we see in the above example is that during the month of monitoring, the highest levels (red) of $PM_{2.5}$ came from the south, at wind speeds between 15 and 20 mph. Moderate levels (yellow) came from other directions at variable wind speeds.

The PM Impact App allows each resident to locate potential sources. Each plot is specific to a location and to a time period. Our community-based results show that in general, the direction of greatest impact is similar for nearby homes. Sources of air pollution can also vary, and residences that are set apart by topographic differences, such as river valleys or hilltop locations, may experience distinct weather patterns.

It is important to check wind speeds in considering potential sources. Low wind speed exposures indicate that the pollution source is close to the monitor. High wind speed exposures generally indicate a source further away.

Exposure Discussion: Putting it all together

Weather affects how pollutants move through communities, and plays a large role in determining exposure levels for residents who live near polluting sources. EHP uses $PM_{2.5}$ as a surrogate chemical for other pollutants in assessing local air exposure levels. $PM_{2.5}$ is a well-studied air toxin and it is known to bind with other air pollutants, increasing potential health impacts. PM monitors such as the Speck provide continuous data, are easy to use and inexpensive, making them ideal for community monitoring projects.

The data from Speck monitoring show how air pollution moves through and around neighborhoods. **We can determine what baseline levels look like, how often peaks occur, their intensity and duration. Most notably, we see that most peaks occur during times of low wind speed and these times predictably occur at night.**[9]

When Speck data is paired with the PM Impact App, residents can see what weather conditions bring $PM_{2.5}$ near each of their homes. This helps them prepare for times of high exposure by closing windows, staying indoors and filtering indoor air. The App also shows which direction pollutants are coming from, which can help in identifying potential sources of pollution.

We know from the NEI that mixtures of chemicals are emitted by compressor stations. VOC sampling provides qualitative information on air pollutants that may travel with PM. Occasional sampling for VOCs is an inexpensive way to show snapshots of chemical pollutants in the air that may be inhaled by residents. Gathering continuous, quantitative data on VOCs would be best, but is cost prohibitive for communities.

The EHP Air Model, using chemical data from the NEI, brings together a year's worth of weather data with reported emissions to predict exposures within 10 km for fully operating compressor stations. The model predicts that peak exposures are likely to occur within 0.5 km of most New York permitted compressor stations approximately 10% of the time over the course of a year. The greatest impacts would be the result of local weather stagnation, which occurs about 10% of the time. Most stagnant weather periods typically occur at night. Large compressor stations, in particular those with Title V permits and higher emissions, have the capacity to impact human health much further afield during times of poor air dilution, again about 10% of the time. Moderate health effects might be felt as far as 5 km (3.1 miles) from these large emissions sources.

The information gained from local air monitoring and understanding local weather patterns, and from modeling based on reported chemical emissions, provides communities with plausible

[9] Times of low wind speed will also occur during weather events such as daytime inversions. High wind speeds can also carry pollutants long distances, by creating a plume of pollutants that does not readily disperse.

estimates of exposures, in the absence of publicly available health assessments. The results put forth in this report show the need for local, continuous air and weather monitoring near these shale gas facilities. Current regulations and monitoring protocols are not designed to detect these kinds of environmental health impacts and are not accurate predictors of exposures for residents living nearby.

NY Project Community Health Assessment

Expansion of compressor stations in rural and urban communities in New York State threatens to expose residents to a mixture of toxic agents. The NY Project community health assessment is designed to determine whether the exposures adversely affect the health of residents.

Two approaches were used to collect health information:

1. an individual health assessment survey, and
2. a standardized survey of individual functional capacity, the SF-36, developed by the Rand Corporation.

Both approaches were used to measure aspects of health status before construction of new emission sources (baseline health data). Initially, the intent was to conduct a second survey after construction and identify health changes when the compressors were operational. A second survey was implemented about 6 months after construction, but compressors were not yet fully functioning to capacity at that time.

Baseline pre-exposure health profiles collected for each community will be available for comparison to post-exposure profiles in the future, after sites are fully operational. Here we examine pre-exposure health results with results from an exposed group in Pennsylvania, and propose a surveillance model applicable to all sites.

The potential scale of increased health effects is estimated through comparison with findings at sites with similar shale gas emissions, in terms of mixtures and amounts in Pennsylvania. In the Marcellus shale region of Pennsylvania, it has been established that a suite of hazardous chemicals are co-released with methane at areas where hydraulically fracked gas is developed, stored and used.[10] The toxic actions of the chemicals emitted are known and a syndrome of health effects has also been identified.[11] Similar health effects have been identified near pipeline compressor stations, such as those reported in Minisink, NY, where a new compressor station had been fully operational for one year before surveys were conducted.

[10] http://www.depgreenport.state.pa.us/powerbiproxy/powerbi/Public/DEP/AQ/PBI/Air_Emissions_Report

[11] Weinberger, Beth, Lydia H. Greiner, Leslie Walleigh, and David Brown. "Health Symptoms in Residents Living near Shale Gas Activity: A Retrospective Record Review from the Environmental Health Project." *Preventive Medicine Reports*8 (December 2017): 112–15. https://doi.org/10.1016/j.pmedr.2017.09.002.

In the present study, health profiles collected from the nine participating locales characterize the current health status in suburban and rural New York State communities, prior to the full operation of newly constructed or expanded compressor stations. The relative risks from fully operating compressor stations are projected. These projections are based on findings in suburban and rural communities where there are similar activities and emissions in Pennsylvania and New York, and on the EHP Air Model of New York State compressor stations (see Exposure section).[12]

2014 Minisink Study: SUMMARY OF HEALTH IMPACTS

EHP collected health information from 35 individuals, 12 of whom were children. Symptoms that developed after the potential exposure period (beginning summer 2013) or worsening pre-existing symptoms without a more plausible cause were reviewed. The predominant health impacts reported were:

- Respiratory problems (22, includes 6 experiencing nosebleeds)
- Neurological problems, (12, all of whom report headaches)
- Dermatological problems (10, skin rashes)
- Overall physical health self-assessments, when compared to a national standard (SF-36), are below normal for 2 out of the 8 individuals who completed the SF-36. Overall mental health and wellbeing levels were below normal for half of the respondents.

The health profile seeks two levels of data:

1. identified symptoms sensitive to the environmental changes; and
2. measureable changes over time which are more likely to be detected by local health providers.

Method of Approach

Locations for the community assessment met three criteria:

1. a compressor station was planned for construction or major expansion of a current compressor station was permitted;
2. time was available to collect pre-exposure health data; and
3. a lead volunteer was identified in the community to contact residents willing to provide health information.

Furthermore, a medical professional volunteer was present who could assist with health intakes.[13] An exposure history was also requested from the participants.

Community health assessments were completed in nine New York State communities.[14] The data constitutes a baseline health assessment, to be available for future health comparisons as well as

[12] An extensive community health assessment conducted in Washington County Pennsylvania identified clinically important observable clinical health symptoms. Similar health effects were found at Minisink where similar chemicals were released

[13] Although children are present and information on their health was collected only adult participant data was used. Children under 17 are not eligible to complete an SF 36.

for this assessment of projected health impacts. Table 8 shows age and gender characteristics for all participants. One hundred and twenty-eight adults completed the pre-construction health surveys.

Table 8. Age and Gender Characteristics of Participants.

County Location	Number	Male	Female	Average Age	Age Range
Chemung	6	3	3	51	31 - 73
Delaware	1		1	28	
Madison	25	12	13	55	22 – 82
Montgomery	18	9	9	48	19 – 84
Niagara	12	5	7	45	18 - 60
Rensselaer	25	11	14	59	33 – 90
Schoharie	7	4	3	54	45 - 60
Sullivan	8	3	5	57	39 – 65
Tompkins	24	13	11	54	19 - 74

The average age of the participants ranged from 45 to 59. The age range of all participants ranged from 19 to 90. There were 60 men and 66 women.

[14] County Health Departments at two sites cooperated in the collection of health data, in Madison County and Rensselaer County. All nine County Health Departments were provided an opportunity to collaborate at all sites.

Findings of Health Intakes

Table 9 summarizes responses from health survey participants. Symptom response rates range from zero to 22 and only reported symptoms are listed.

Table 9. Symptoms reported in New York Project Health Surveys.

System	Symptom reported	# of positive responses	Percentage N=128
Cardiovascular	Increased/decreased blood pressure	15	11.7
	Heart palpitations/flutters	8	6.25
	Decreased exercise tolerance	3	2.34
	Chest pain	3	2.34
Respiratory	Cough	8	6.25
	Shortness of breath	5	3.9
	Wheezing/difficulty breathing	5	3.9
Gastrointestinal	Heart burn/ indigestion	16	12.5
	Frequent diarrhea/ constipation	8	6.25
	Nausea/vomiting/abdominal pain	5	3.9
	Decreased appetite	2	1.56
	Stomach/bowel symptoms other	8	6.25
Urinary	Problems with urination	6	4.69
Reproductive	Infertility/loss of pregnancy	2	1.56
	Period/menopause issues	8	6.25
	Low testosterone	4	3.13
Endocrine	Increased sweating/thirst	1	0.78
	Hair loss	2	1.56
Neurological	Headache	20	15.6
	Frequent falls/balance difficulty	6	4.69
	Dizziness	4	3.13
	Tingling/numbness	13	10.2
	Confusion/memory loss	5	3.9
	Concentration difficulties	6	4.69
	Other neurological symptoms	7	5.47
Musculoskeletal	Painful/swollen joints	20	15.6
	Muscle aches/cramps	13	10.2
Hematological	Easy bruising	9	7.03
	Prolonged bleeding/difficulty clotting	2	1.56
	Nose bleeds	2	1.56
Psychological	Stress	3	2.34
Constitutional	Weight changes	8	6.25
	Fatigue/weakness	10	7.81
	Fever/chills/night sweats	8	6.25
Dermatological	Skin rash/hives/blisters	12	9.38
	Skin irritation/itching/burning	4	3.13
	Dry skin	14	10.9
Ears, eyes, nose & throat	Irritation/itchy/burning eyes	15	11.7
	Vision problems/blurry/floaters	27	21.1
	Hearing loss/tinnitus	20	15.6
	Runny nose/colds	13	10.2
	Sinus problems	16	12.5
	Sore throat/irritation/hoarseness	7	5.47
	Dry mouth/mouth irritation	11	8.59
	Other EEN&T Symptoms	4	3.13

Ear, eye, nose and throat, respiratory, neurological and constitutional symptoms are reported in over 5% of residents. The symptoms reported likely reflect the typical status of an unexposed population in suburban and rural New York State.[15]

In order to identify which health symptoms are potentially associated with shale gas emissions, the nine most frequently reported symptoms in the New York project are compared with symptoms reported at locations known to have relatively high shale gas emissions in PA.

Table 10 shows the rate of responses from the New York communities compared to the response rates in the Pennsylvania exposed group. Certain symptom frequencies are similar between groups while others are higher in the group that experienced higher exposures.

The increase in response rates for some symptoms in Pennsylvania suggests a possible interaction with shale gas activity. Those health parameters are worth following in communities where compressor stations are fully functioning.

Table 10. Comparison of the nine most reported symptoms in New York pre-exposed residents and Pennsylvania exposed residents, based on EHP health surveys.

Health Survey response		New York N=128	Pennsylvania N=60	Comparison
System	**Symptom**	**Percent of Pre-exposed group**	**Percent of Exposed group**	**Symptoms elevated in exposed groups**
Eyes, ears, nose & throat	Vision problems	21	--	
	Sinus problems	**13**	**26**	**Elevated**
	Burning eyes	**12**	**18**	**Elevated**
	Hearing issues	16	16	
	Runny nose	**10**	**18**	**Elevated**
	Dry mouth	9	--	
Neurological	**Headache**	**16**	**37**	**Elevated**
Musculoskeletal	Painful joints	16	14	
	Muscle aches	10	13	

The difference between the reporting rate of the following 11 symptoms at Pennsylvania shale gas exposure locations and in the New York pre-exposed population, suggests that these are potentially useful indicators of a health effect related to exposures. Four of these

[15] Centers for Disease Control and Prevention Behavioral Risk Factor Surveillance System prevalence rates for some of these systems can be found here: https://www.cdc.gov/brfss/index.html

symptoms are derived from Table 10. The remaining eight are derived from high response rates reported in the PA dataset.

Table 11. Comparison of eleven symptoms; the top eight reported in Pennsylvania health surveys (exposed group) and four top symptoms from New York health surveys (pre-exposed group).

Health Survey Response		New York N=128	Pennsylvania N=60
System	**Symptom**	**Percent of Pre-exposed group**	**Percent of Exposed group**
Eyes, ears, nose & throat	Irritation/itchy/burning eyes	15	39
	Sore throat	7	37
	Sinus problems	16	26
	Runny nose/colds	13	18
Respiratory	Shortness of breath	5	32
	Cough	8	32
	Wheeze	5	28
Neurological	Headache	20	37
	Dizziness	4	14
Constitutional	Fatigue/weakness	10	21
Cardiovascular	Heart palpitations/flutters	8	15

Self-assessment of factors that suggest changes in physical and mental health
Individual health impacts are manifested in different ways, determined in part by the physiological actions of chemicals in the mixture of air pollutants and by the susceptibility of the individuals exposed. Emissions from shale gas facilities as environmental stressors could influence an individual's physical health by its action on various organ systems, as well as affecting mental health. The Rand Corporation developed the SF-36 survey, a survey instrument using action-specific questions. It is designed to measure overall health, as opposed to targeting a specific disease or area of the body. This self-assessment tool is typically used by the medical community to measure changes in physical and mental health status over time. The SF-36 health status parameters are reported in a standardized, statistical format. Individuals are compared to physical health or mental health parameters based on a national norm.

A total of 128 NY participants completed the Rand SF-36 survey.[16] The overall results are presented in Table 12 and compared to overall SF-36 results from a group of heavily exposed individuals in PA.

[16] Each intake form and SF-36 report was reviewed by a health professional to assure that a medical condition that required immediate actions was not present. Each resident received a report within 90 days irrespective of the health information received. Residents were informed that this was not a substitute for annual health exams.

Table 12 shows the fraction of the population in which the domain or composite scores fell below a benchmark value of 40, which marks a lower than average health response and indicates a potential health issue. The exposed population in Pennsylvania shows higher percentages of health scores below the national average.

Table 12. SF-36 summary data on health parameters for the New York pre-exposure locations and the Pennsylvania exposed populations.[17] Results show the percent of participants who scored below the national average for these parameters.

SF-36 parameter	New York N=128	Pennsylvania N=45
	Percent of Pre-exposed group	Percent of Exposed group
Physical health composite score	**3**	**38**
General health	5	42
Physical function	7	38
Bodily pain	8	42
Vitality (fatigue)	5	51
Mental health composite score	**6**	**36**
Role function	8	49
Social function	3	47
Mental health	3	38
Emotional role	8	44

It is possible that this survey tool, if used periodically by residents living near natural gas compressor stations, can serve as a screening tool for specific health impacts. EHP also recommends adding a short screening tool for the specific symptoms that are associated with shale gas exposures based on our health assessments in Pennsylvania. The SF-36 survey and the screening tool can be completed by individuals in 10-15 minutes. If completed by residents every six months and reviewed by primary care physicians, health effects can be quickly identified and addressed.

[17]The RAND 36-Item Health Survey (Version 1.0) taps eight health concepts: physical functioning, bodily pain, role limitations due to physical health problems, role limitations due to personal or emotional problems, emotional well-being, social functioning, energy/fatigue*, and general health perceptions. It also includes a single item that provides an indication of perceived change in health. These 36 items are identical to the MOS SF-36 described in Ware and Sherbourne (1992). They were adapted from longer instruments completed by patients participating in the Medical Outcomes Study (MOS), an observational study of variations in physician practice styles and patient outcomes in different systems of health care delivery (Hays & Shapiro, 1992; Stewart, Sherbourne, Hays, et al., 1992

Conclusion

EHP has concluded its pre-exposure assessment of air and health impacts from shale gas compressor stations in New York communities. Based on three years of community monitoring and air exposure modeling using available compressor emissions data, we find that these communities are in the early stages of an emerging public health problem related to shale gas emissions from transport pipeline compressor stations.

In collaboration with participants, we have:

- Identified current air quality levels, from residential air monitoring of $PM_{2.5}$ and VOCs;
- Identified potential air exposures using the EHP Air Model which predicts impacts from fully operational sites; and
- Projected future health impacts associated with exposure to fully operating compressor stations.

Through our health data collection, we have described relatively healthy New York communities and compared their health status to a highly exposed population in Pennsylvania. Our work on shale gas exposures and public health in Pennsylvania has identified specific health effects related to a suite of chemicals found in shale gas that are known to affect the respiratory, neurological and cardiovascular systems as well as the ears, eyes, nose and throat system. Through a toxics risk analysis, a discreet set of health symptoms to watch for in New York State has also been identified.

Looking ahead, if compressor stations increase the amount of shale gas moving through New York's pipelines, we can predict an increase in compressor station emissions, and a consequent increase in exposures. To determine the intensity and duration of these exposures and health impacts, we strongly advise continuous monitoring of known toxic chemical emissions and periodic community health surveys to monitor health symptoms related to shale gas exposure. **Only with continuous monitoring can the review and analysis of past pollution events take place, so that actual exposures can be documented.**

Recommendations

Home health recommendations

1. Be aware of weather patterns – learn where nearby sources of pollution are located in reference to your home. When the wind is blowing from the source to your home you are more likely to be exposed to air pollutants. Times of low wind speed may also cause poor air quality.

We recommend:

- Closing your windows
- Filtering indoor air with either whole house filters or room air filters
- Keeping your indoor environment as dust free as possible. Remove shoes and soiled clothing to keep dust out of the house.

What to do within your community

1. ***A local public agency should conduct a Community Health Impact Assessment (HIA). An HIA helps communities answer three important questions:***

- What chemicals are being emitted or leaked from the local compressor station (or from a proposed site)?
- Are people being exposed to emissions?
- What are the health effects from exposures?

Answers to these questions can help decision-makers make informed decisions. EHP has a template for conducting an HIA for compressor stations. The template is available here: https://www.environmentalhealthproject.org/health-impact-assessment

2. Push for continuous air monitoring near the compressor station.

- Town, County and/or State agencies should take public health actions by devising neighborhood monitoring strategies.
- $PM_{2.5}$ monitors are inexpensive and provide continuous, real time data for consistent air monitoring. Continuous VOC monitoring, while more costly, would define the set of air toxics most likely to cause health effects.
- Periodic reviews of PM and VOC exposures are necessary, especially during blowdown events and times of poor air quality. Only with continuous monitoring can past events be reviewed and analyzed to measure actual exposure levels
- Use the PM impact App as needed to identify local sources and impacts (available through EHP).

3. Push for regulations on industrial air emissions

- Prohibit venting and blowdowns during times of poor air dilution.
- Insist on notifications in advance of large releases including blowdowns within 1 ¼ miles and notification of accidental releases.
- Require transparency on all compressor station emissions levels.

- Require best available technology to be used at compressor stations and metering stations.

4.Track community health effects

- Conduct periodic health screening surveys such as the SF-36 and follow up as necessary with more detailed health surveys.
- Join the EHP Shale Gas Health Registry. EHP's national Shale Health Registry documents exposures and health impacts from anyone living within five miles of a shale gas or oil site. This data from the registry will help us to communicate to researchers, public officials and communities about the health risks posed by these sites. https://www.environmentalhealthproject.org/health-effects-registry

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Appendix 1. SITE SELECTION AND PIPELINE DESCRIPTIONS

The criteria for a community's inclusion in the New York Environmental Health Monitoring Project (NY project) are:

> 1) a compressor site permitted or awaiting permits, but not yet constructed or expanded (in the case of existing compressors);
> 2) at least four participating households within two kilometers (1.25 miles) of a compressor station site; and
> 3) demonstrated capacity on the part of the partnering community that it can implement the protocol with close guidance from the EHP team. Participating communities conduct both pre-construction (or pre-expansion) health and air quality data collection and post-construction (or post-expansion) data collection.

Nine communities along five different pipelines are involved in the NY project. Each one invited EHP to conduct an environmental health assessment in the residential area surrounding either an existing or proposed compressor station site in order to address health concerns raised by residents. All sites are located along existing pipelines or proposed expansions of pipelines.

Dominion Energy's New Market Project

The New Market Project travels through four of our partner communities bringing shale gas north into New York, primarily from Pennsylvania (PA) and then east across the state. The Madison County Department of Health contacted EHP when Dominion applied for permits to construct the new Sheds compressor station. The County DOH was our first New York partner in this project and worked with EHP to design and conduct pre- and post- monitoring and health surveys. The County also conducted its own monitoring during the construction of the station. In Chemung County, which borders PA, a new compressor station was proposed and built in the village of Horseheads. To the north, in Tompkins County, the Borger compressor station was permitted for expansion. And in Montgomery County, the Brookmans Corners compressor station was slated for expansion.

Residents in the four communities took part in pre-construction or pre-expansion air monitoring and health surveys between Fall 2015 and Spring 2017. Construction at all four sites was complete by the fall of 2017 and post-construction monitoring occurred about six months later in 2018. The second round of monitoring occurred in late spring and early summer and residents reported that the compressor stations were not fully operating, if at all, during this time.

Millennium Pipeline's Eastern System

The Eastern System Upgrade along the Millennium pipeline runs from Pennsylvania into New York along its southern tier, heading east toward New England ports. The Hungry Hill compressor station was built in Delaware County in 2014 and was already causing concern from residents experiencing episodic health symptoms. A proposed expansion of the station was under review. EHP worked with residents to conduct pre-construction air monitoring around the compressor station in 2016. The expansion is nearly complete. In

Sullivan County to the east, in the town of Eldred, the construction of the new Eldred compressor station has just been completed. Pre-construction monitoring was conducted here in 2016. These two sites are scheduled for post-construction monitoring about 6 months from completion.

Tennessee Gas Pipeline / Kinder Morgan's Northeast Energy Direct
Northeast Direct was a proposed expansion of Tennessee Gas Pipeline's network in New York and other states to carry shale gas to New England ports and also north to Canada. The Rensselaer County Department of Health partnered with EHP to conduct pre-construction protocols in 2015, after a new compressor station was proposed in the Village of Nassau. The pipeline expansion effort was halted in May 2016 and the application for permits rescinded, due in part to a lack of available markets. There was also strong opposition in affected communities of New York, New Hampshire and Massachusetts.

National Fuel's Northern Access Expansion
The Northern Access expansion of National Fuel's pipeline carries shale gas from northern Pennsylvania to the Buffalo region and into Canada. A proposed compressor station in the town of North Tonowanda led local residents to reach out to EHP. In 2015 pre-construction evaluations were conducted. The NYDEC denied water permits for the pipeline expansion in 2017. FERC over-ruled the denial in 2018.

Constitution Pipeline Expansion
The Constitution pipeline was proposed to carry gas north from Pennsylvania to join the Iroquois pipeline in Schoharie County. At the request of residents in the town of Wright, where a new compressor was proposed in close proximity to an existing station, which would also be expanded, EHP conducted pre-construction evaluations. The NYDEC denied the pipeline a water permit in 2016. This denial was contested in court but was upheld and the pipeline expansion currently remains on hold.

Appendix 2. METHODS AND ANALYSIS

Methodology

At each New York Environmental Health Monitoring Project site, EHP works closely with one or two community liaisons, who may be local public officials or local community organizers. The community liaison is responsible for recruiting participants and disseminating information, forms and equipment. EHP conducts orientation meetings before monitoring begins, and again at the close of each phase of monitoring and analysis.

$PM_{2.5}$ monitoring. Central to the air exposure evaluation is particulate matter monitoring using the Speck Sensor, a continuous monitoring device. The Speck samples the air every minute, specifically measuring the presence of $PM_{2.5}$, which are particles that have a diameter of less than 2.5 micrometers (about 1/30th the size of a human hair).[18] To establish typical patterns of weather variability and its impact on $PM_{2.5}$ exposures, EHP's standard air monitoring protocols include 32 days of continuous, 1-minute sampling of $PM_{2.5}$ inside and outside residences within 1.25 miles of a compressor station site. Monitors must be carefully placed away from known sources of $PM_{2.5}$ (e.g., not near gas stoves, fireplaces, garages).[19]

VOC data collection**.** Summa canisters, formaldehyde badges and hydrogen sulfide (H_2S) badges are used to sample for VOCs. Canisters are placed as close as possible to the compressor site, or at a nearby participating residence, at a location downwind from the site. The badges are placed with the summa canisters. In each community a few individuals are instructed by EHP on deployment methods. The protocol for deploying SUMMA canisters and badges for 12 or 24 hour periods includes two criteria: One, the wind should be blowing predominantly from the direction of the compressor station site in question towards the particular testing site; Two, the wind speed should be low (0-7 mph) the majority of the time, resulting in poor air diffusion (and consequently a higher concentration of chemical contaminants per $meter^3$ of air). Weather predictions are taken from the NOAA weather website for the relevant location, using the hourly prediction table. The U.S. EPA TO-15 sampling analysis and badge analyses are conducted by a certified laboratory.

Air Modeling. EHP has developed an air screening model (The EHP Air Model) to provide communities with estimates of exposure levels within a radius of 10km from a local site – in this case, compressor stations. This analysis compliments the air monitoring conducted by the residents and can be directly applied to the entire community.

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[18] The Speck is a low cost monitor which allows EHP to carry out detailed analysis of short and long term exposure.

[19] $PM_{2.5}$ is important on its own but is also an effective surrogate for exposures to chemicals emitted at compressor stations because the levels of particulates relative to other emitted chemicals is known from the NEI reports on Title V compressor stations.

Health survey data collection. During the air monitoring periods (Phases 1 and 2), health data is collected. The assessment of health status includes a health survey, designed by EHP specifically to be used near shale development sites, and the SF-36, a nationally validated health assessment tool developed by the Rand Corporation. The SF-36 was designed for use in clinical practice and research, health policy evaluations, and general population surveys.

Sites either had a designated health care professional administer the forms individually, or they used a secure electronic form using Survey Monkey. If a local health professional was involved, that person would review the information for concerning symptoms. If forms were filled out on-line, they were reviewed by EHP's physician-researcher.

Data Analysis

The EHP Air Model. Two factors determine the concentration levels of air toxics reaching a nearby residence: the amount emitted from the source and the rate of dilution as the pollutants move from the point of emission to the exposed individual(s). The EHP Air Model uses these two factors to estimate the hourly air levels of pollutants to which a residence is exposed. The concentrations of pollutants to which residents are exposed are based on:

1. Three categories of weather data: 1) hourly wind speed, 2) wind direction, and 3) cloud cover.[20]
2. A base estimate of $PM_{2.5}$ emissions from shale gas compressor stations of 300 grams/hour. This estimate is based on a literature review on compressor emissions conducted by EHP. The base estimate is then scaled up or down depending on the size of the site.[21]
3. The emissions level used in scaling the model, is based on the top 5 chemicals emitted from New York compressor stations as reported to the National Emissions Inventory (NEI) (after methane and carbon dioxide). These are nitrogen oxides, carbon monoxide, volatile organic compounds, formaldehyde and particulate matter and together make up approximately 95% of reported emissions.[22]

The median hourly air concentration of emissions and the 90th percentile of the annual hourly air levels are used in the analysis to evaluate the human health hazard at distances of 0.1km, 0.5km, 1km, 2km, 5km, and 10km, in each direction from the emissions source. This provides an estimate of the mid-range of exposure at each house as well as the highest likely exposures.

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[20] Archived data is stored by NOAA and is publicly available https://www.ncdc.noaa.gov/cdo-web/datatools/lcd . A period of 12 months is used in the calculation.

[21] In this project sites are factored by 5 for the large Title V site and by 2.5 for the smaller facility sites.

[22]Russo, P.N., D.O. Carpenter. 2017. Health Effects Associated with Stack Chemical Emissions from NYS Natural Gas Compressor Stations: 2008-2014, A Technical Report Prepared for the Southwest Pennsylvania Health Project. https://www.environmentalhealthproject.org/resources

This project includes compressor stations with two types of air pollution permits. The majority of NY compressors have Air State Facility (ASF) permits. ASF permits are issued to facilities that are not considered to be major (as defined in the department's regulations), but that meet certain federal and state criteria. These are generally large facilities with actual emissions exceeding 50 percent of the level that would make them major "Title V" sites but their potential to emit does not place them in the major category.[23] ASF sites are not regulated as strictly as larger polluting sites, making it difficult for the public to assess actual emissions.

There are currently 18 NY compressor stations with a Title V facility permit. Title V facility permits are issued to facilities that are judged to be major under the department's regulations, or that are subject to a standard or other requirements regulating hazardous air pollutants or to federal acid rain program requirements.[24]

To provide air model estimates of emissions for ASF compressor stations, EHP used the publicly available data from the NEI of the lowest ranking Title V compressor station in NY as the base case. There are 18 NY compressor stations with Title V permits and the smallest of these is TGPC CS 233 in Livingston County.

ASF compressor stations emit between 50% - 99% of the threshold for a major permit. We provide the range of possible exposure estimates based on 50 – 100% of the emissions data for compressor station TGCP CS 233.

The emissions level we use in the model includes the top 5 chemicals emitted after methane and carbon dioxide. These are nitrogen oxides, carbon monoxide, volatile organic compounds, formaldehyde and particulate matter.[25]

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[23] State facility permits also require the use of permit conditions to

- limit emissions below thresholds that would make them subject to certain state or federal requirements
- They have been granted variances under the department's air regulations, or
- They are new facilities that are subject to New Source Performance Standards (NSPS) or that emit hazardous air pollutants.

[24] Title V permits reduce violations of air pollution laws and improve enforcement of those laws by:

- Recording in one document all of the air pollution control requirements that apply to the source. This gives members of the public, regulators, and the source a clear picture of what the facility is required to do to keep its air pollution under the legal limits.
- Requiring the source to make regular reports on how it is tracking its emissions of pollution and the controls it is using to limit its emissions. These reports are public information, and you can get them from the permitting authority.
- Adding monitoring, testing, or record keeping requirements, where needed to assure that the source complies with its emission limits or other pollution control requirements.
- Requiring the source to certify each year whether or not it has met the air pollution requirements in its title V permit. These certifications are public information.
- Making the terms of the title V permit federally enforceable. This means that EPA and the public can enforce the terms of the permit, along with the State.

(Source: NYSDEC)

[25] Russo, P.M., D.O. Carpenter. 2017. Health Effects Associated with Stack Chemical Emissions from NYS Natural Gas Compressor Stations: 2008-2014, A Technical Report Prepared for the Southwest Pennsylvania Health Project. https://www.environmentalhealthproject.org/resources

Limitations:

1. There could be major terrain effects or effects from large bodies of water that are not represented in the model.
2. The nearest weather data that provides all needed components is used, but there could be local conditions that change the weather dilution.
3. The Air Screening Model is based on an annual emissions estimate and assumes that emissions are uniform over the reporting year. If the emissions are not uniform the median and peak (90^{th} percentile) ambient air estimates would be low. Thus, this should not be considered to be a worst-case scenario.

EHP Air Model Results for State Facility permitted compressor stations.

The Livingston County compressor station's reported emissions for top five contaminants after methane and carbon dioxide (NOx, CO, VOCs, Formaldehyde, and PM) is approximately 1588 grams/hour [about 32,000 pounds/year]. Air model results are shown in Table A. We consider these estimated exposures to be close to the upper limit of ASF permit levels (i.e. larger ASF stations would approach these levels). More accurate results for specific compressor stations require using local weather data close to the emissions source, and having specific emissions rates.

Table A. NY Title V Compressor Station Air Screening Model for exposures within 10 kilometers, representing upper bound limits for ASF compressor sites. Results in μg/m^3.

Wind Direction	0.1km	0.5 km	1km	2km	3km	5km	10km
NORTH 26% of time per year							
Median	3750	500	220	70	40	10	2.5
Max	21000	3625	1750	750	495	230	85
90th percentile	21000	3625	1750	750	495	230	85
EAST 12% of time per year							
Median	4250	500	220	85	40	15	2.5
Max	21000	3625	1750	750	495	230	85
90th	15000	2500	1250	500	355	165	60
SOUTH 20% of time per year							
Median	4250	500	220	85	40	15	2.5
Max	21000	3625	1750	750	495	230	85
90th percentile	15000	2500	1250	500	355	165	60
WEST 43% of time per year							
Median	3625	500	185	70	40	10	2.5
Max	21000	3625	1750	750	495	230	85
90th percentile	15000	2500	1250	500	355	165	60
All Year							
Average	6803.8	1092.7	477.55	202.95	127.35	57	19
Median	4250	500	220	85	40	15	2.5
Max	21000	3625	1750	750	495	230	85
90th percentile	21000	3625	1750	750	495	230	85

Table B shows 50% of the above Title V compressor's estimated emissions. We consider the estimated exposures in Table B to be close to the **lower** limit of State Facility permit levels (about 750 grams/hour or 15,000 pounds/year). Smaller ASF compressor stations would emit near these levels. Results in $\mu g/m^3$.

Table B. Air Screening Model for compressor stations with New York ASF permits, exposures within 10 kilometers showing lower bound limits. Results in $\mu g/m^3$.

Distance	0.1km	0.5km	1km	2km	3km	5km	10km
NORTH 26% of time per year							
Median	1875	250	110	35	20	5	1
Max	10500	1812	875	375	247.5	115	43
90th percentile	10500	1812	875	375	247.5	115	43
EAST 12% of time per year							
Median	2125	250	110	42.5	20	7.5	1
Max	10500	181	875	375	248	115	43
90^{th}	7500	1250	625	250	177.5	82.5	30
SOUTH 20% of time per year							
Median	2125	250	110	42.5	20	7.5	1
Max	10500	1813	875	375	248	115	43
90th percentile	7500	1250	625	250	177.5	82.5	30
WEST 43% of time per year							
Median	1812	250	92.5	35	20	5	1
Max	10500	1813	875	375	248	115	43
Min	688	43	10	2.5	1	1	1
90th percentile	7500	1250	625	250	178	83	30
All Year							
Average	3402	546	238	101	64	29	10
Median	2125	250	110	43	20	8	1
Max	10500	1813	875	375	248	115	43
90th percentile	10500	1813	875	375	248	115	43

Table C. Air Screening Model Results for Ithaca's Borger Title V permitted compressor station. Results in μg/m³.

Wind direction	0.1km	0.5km	1km	2km	3km	5km	10km
North 31% of time per year							
Median	13500	1750	690	260	170	50	10
Max	42000	7250	3500	1500	990	460	170
90th percentile	42000	7250	3500	1500	990	460	170
EAST 17% of time per year							
Median	30000	5000	2500	1000	710	330	120
Max	42000	7250	3500	1500	990	460	170
90th percentile	42000	7250	3500	1500	990	460	170
South 24% of time per year							
Median	7250	1000	370	120	70	20	5
Max	42000	7250	3500	1500	990	460	170
90th percentile	26000	5000	2000	1000	650	310	90
WEST 27% of time per year							
Median	6300	870	320	120	60	20	5
Max	42000	7250	3500	1500	990	460	170
90th percentile	18500	3500	1500	750	460	220	70
ALL YEAR							
Average	15360	2500	1100	470	300	130	40
Median	8500	1000	440	170	80	30	5
Max	42000	7250	3500	1500	990	460	170
90th percentile	42000	7250	3500	1500	990	460	170

Speck Index

The Speck Index, the analytic approach developed by EHP, transforms complex time-series data into summary statistics. The Speck instrument measures $PM_{2.5}$ levels in 1-minute intervals. The Index results show the patterns of exposure experienced by residents near their homes. These patterns can be used to evaluate the effects of changes in PM variability and magnitude, and can be linked to dose-related health responses. It provides an effective method for assessing health impacts from localized air pollution exposures.

The Speck Index produces five statistics from the analysis of 32 days of minute data:

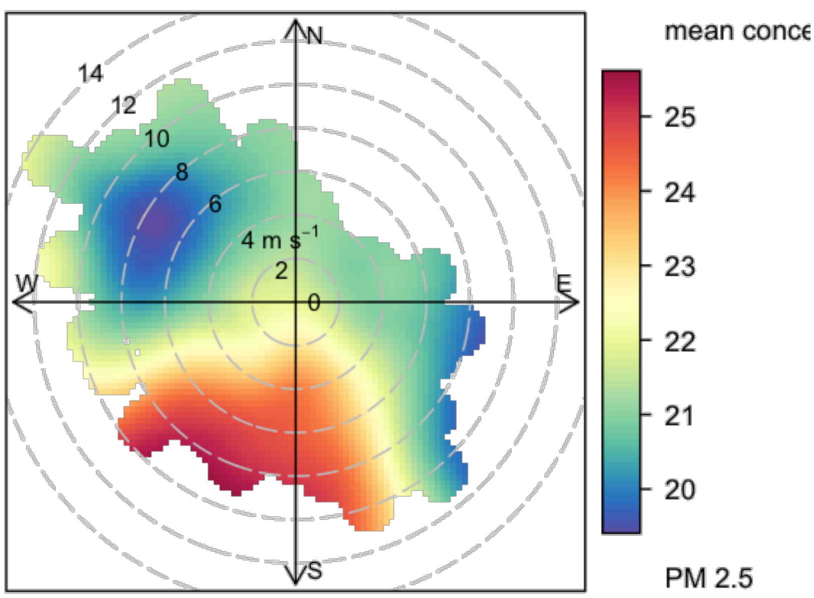
- **Peak frequency:** Average number of times concentrations are higher than two standard deviations above the average in a 24-hour period.

- **Peak duration:** Average peak length in minutes.[26]
- **Time between peaks:** Average number of hours between the beginning of one peak and the beginning of the next peak.
- **Baseline:** 35th percentile of all values in a 32-day period. This is the level of $PM_{2.5}$ that the monitor finds 35% of the time. This value was selected as the most common point at which values began to increase after a stable phase.
- **Accumulated particle concentration:** Average of the PM levels area under the curve of peaks in a 24-hour day.[27]

PM Impact App

The PM Impact App, developed for EHP, merges local, time-synchronized, weather data from nearby airports with Speck data from each residence. The resulting polar plot demonstrates for residents the direction and wind speeds that correlate with various levels of $PM_{2.5}$ at their location.

Figure A. Example of PM Impact App polar plot



The image displays three important aspects of an outdoor Speck monitor's results: **the direction** from which $PM_{2.5}$ comes from; **the intensity** of the $PM_{2.5}$ measurements; and **the wind conditions** at the times of exposure. In the image, the Speck monitor is located in the center where the lines cross. The endpoints of the lines represent the cardinal directions of North, South, East, and West with North at the top. The intensity of $PM_{2.5}$ levels is shown in the range of colors from blue (low exposure) to red (high exposure). The concentric circles represent the wind speed, with low wind speed near the center and higher wind speeds further out.

[26] Calculated by multiplying the number of consecutive z-score values at or above 2 by the length of time a single peak lasts.
[27] An algebraic variant of the cumulative concentration metric proposed by Oh et al 2012.

VOC data interpretation

VOC sampling results provide qualitative data on types of chemical exposures that may be linked to $PM_{2.5}$ exposure through the adsorption of chemicals to PM. We check actual weather conditions reported to NOAA that occur during the sampling period. If poor air mixing (low diffusion) occurs more than 50% of the sampling period, the results are considered as good estimates of exposure on poor air quality days. If low diffusion occurs less than 50% of the time, the air quality is considered good. In that case, reported levels would be multiplied by three to reflect expected peak exposures during poor air quality days (with low mixing).

Results shown in this report were collected during low diffusion periods of more than 50%, thus no scaling for peak exposures was applied. The tables below are identical to those in the main body of this report with the inclusion of information on sampling conditions.

Tables 6 a-c. show VOC sampling results near compressor stations located in three counties along the Dominion Pipeline New Market project.

Table 6a. Shows results from one pre-expansion sample during operation, and 2 post-expansion samples during no or low operation status.

Montgomery County, Brookmans Corners (existing, expanded)
Testing Dates (Pre): 5/25/16, 12 hours (overnight)
Testing Dates (Post): 8/9/18, 24 hours
Weather Conditions (Pre): poor diffusion period (100% low wind speed)
Weather Conditions (Post): poor diffusion period (67% low wind speed)

Chemical	$\mu g/m^3$ Pre-expansion operating	$\mu g/m^3$ Post expansion No or low operation	$\mu g/m^3$ Post expansion No or low operation
Acetone	19	7.6	5.96
Dichlorodifluoromethane	1.9	ND	ND
Naphthalene	0.76	ND	ND
Propene	0.79	ND	ND
Toluene	0.83	6.33	ND
Trichlorofluoromethane	1.0	ND	ND
1,3,5-Trimethylbenzene	0.89	ND	ND
Vinyl Acetate	6.8	ND	ND

Table 6b. Shows results from two pre-expansion samples during operation, and 2 post-expansion samples during no or low operation status.

Tompkins County, Borger Station (existing, expanded) **Testing Dates (Pre):** 5/31/17, 6/5/17 **Testing Dates (Post):** 6/16/18, 6/26/18 **Length of Testing Periods:** 24 hours **Weather Conditions (Pre):** poor diffusion period (67% low wind speed), poor diffusion period (71% low wind speed) **Weather Conditions (Post):** poor diffusion period (92% low wind speed), poor diffusion period (71% low wind speed)				
Chemical	μg/m³ Pre-expansion operating	μg/m³ Pre-expansion operating	μg/m³ Post – expansion No or low operation	μg/m³ Post – expansion No or low operation
Acetone	ND	ND	10.3	5.06
Benzene	3.3	6.4	ND	ND
Chloromethane	ND	ND	1.12	1.09
Dichlorodifluoromethane	2.2	2.6	ND	ND
Ethanol	11	17	ND	ND
Ethyl Acetate	ND	2.6	ND	ND
Ethylbenzene	1.8	3.7	ND	ND
4-Ethyltoluene	ND	0.92	ND	ND
n-Heptane	1.1	2	ND	ND
Hexane	ND	ND	23.1	ND
n-Hexane	4.2	9.9	ND	ND
Methylene chloride	ND	ND	34.2	ND
alpha-Pinene	ND	1.2	ND	ND
Propene	1.1	2.4	ND	ND
Toluene	12	26	ND	2
Trichlorofluoromethane	1.1	1.3	ND	ND
1,2,4-Trimethylbenzene	1.9	3.2	ND	ND
m,p-xylenes	7.4	14	ND	ND
o-xylene	2.8	5.5	ND	ND

Table 6c. Shows results from one pre-construction sample and 2 post-construction sample during no or low operation status.

Chemung County, Horseheads (new construction) **Testing Dates (Pre):** 9/12/16 **Testing Dates (Post):** 6/8/18, 6/25/18 **Length of Testing Periods:** 24 hours **Weather Conditions (Pre):** poor diffusion period (100% low wind speed) **Weather Conditions (Post):** poor diffusion period (79% low wind speed), poor diffusion period (54% low wind speed)			
Chemical	$\mu g/m^3$	$\mu g/m^3$	$\mu g/m^3$
	Pre-const. **No compressor**	Post construction No or low operation	Post const. No or low operation
Acetone	ND	14.6	8.3
Chloromethane	ND	1.18	1.24
Dichlorodifluoromethane	2.3	2.52	2.72
Ethyl Acetate	3.3	ND	ND
Propene	2.1	ND	ND
Methylene chloride	ND	23.3	8.49
Trichlorofluoromethane	1.2	ND	ND
2-Propanol	ND	8.36	2.48

Hydrogen sulfide and formaldehyde were not detected at any sites. The method reporting limit (MRL) on the samples taken may have been too high for detection of low amounts. Reporting limits were 0.57 $\mu g/m^3$ and 0.2 $\mu g/m^3$, respectively.

Appendix 3. RATIONALE FOR EHP'S RISK GUIDANCE TABLE

Risk guidance for Air Model Exposure Estimates in Ambient Air
David Brown, ScD.
January 7, 2018

Summary:

The majority of air emissions from shale gas facilities are composed of five toxic chemicals. This analysis is an estimate of the air levels at which the toxic actions would occur and identifies the possible symptoms experienced. The findings show:

Table 3. Exposure levels of the mixture (NO_x, CO, VOCs, Formaldehyde, PM) emitted from natural gas compressor stations that can elicit health symptoms. Levels reported in ($\mu g/m^3$)

Exposure	Air level	Possible symptoms experienced	Physical system affected
Low	less than 500 $\mu g/m^3$	Eye and throat irritation	Ears, eyes, nose and throat
Moderate	500 to 1000 $\mu g/m^3$	Eye and throat irritation, headache	Ears, eyes, nose and throat; neurological
High	1000 to 2500 $\mu g/m^3$	Eye and throat irritation, headache, shortness of breath, palpitations, chest pain, changes in blood pressure and/or heart rate	Ears, eyes, nose and throat; neurological, respiratory, cardiovascular
Extreme	2500 to 5000 $\mu g/m^3$ and above	Eye, nose, throat irritation, headache, shortness of breath, palpitations, chest pain, changes in blood pressure and/or heart rate, impaired cognitive function such as confusion and difficulty concentrating	Ears, eyes, nose and throat; neurological, respiratory, and worsening cardiovascular effects

Introduction:

Air emissions from shale gas facilities are composed primarily of five toxic chemicals, after methane and CO2: nitrogen oxides (NOx), Carbon monoxide (CO), volatile organic compounds (VOCs), particulate matter ($PM_{2.5}$) and Formaldehyde in these approximate percentages; 40%, 30%, 12%, 3%, and 3%. The toxic effect from high exposures to this mixture is determined by the proportions present.

The purpose of this analysis is to estimate the air levels at which toxic actions would occur and to identify the possible symptoms experienced when exposed to this mixture.

Rationale:

Exposure. Exposure modeling of ambient air levels of the mixture in 130 residential locations in Washington County, Pennsylvania indicate median hourly air levels at a maximum of 10,000 $\mu g/m^3$ and 90th percentile levels up to 30,000 $\mu g/m^3$. $PM_{2.5}$ monitoring of outside air at over 100 residences with 10 or more natural gas sources within 2 miles frequently ranged up to 80 to 100 $\mu g/m^3$. The $PM_{2.5}$ monitoring levels are consistent with chemical mixture levels of 2,000 to 5,000 $\mu g/m^3$ in the ambient air.

This analysis, therefore, is focused on the health effects potentially induced by exposure to one hour or more of ambient air concentrations of the mixture in the 10,000 to 30,000 $\mu g/m^3$ range.

Field measures using continuous monitoring of $PM_{2.5}$ indicate that duration of peak exposures (defined as levels 2 sigma above the mean) ranges from 20 minutes to several hours. The median value is 29 minutes. Occurrence of peaks range from 2 to 5 per 24 hours with a median of 2.3 hours.

Characterization of the toxic actions of components. Immediate toxic actions of air exposure to chemicals are frequently addressed in worker environments. Four of the chemical components in the mixture are considered in work place safety guidance. For one component, $PM_{2.5}$, the immediate actions are considered in the EPA Air Quality Index. These reference values form the basis of this analysis.

VOCs are by definition a mixture of chemicals that are released into the air. Ambient air levels of VOCs have been measured near shale gas well sites and the chemical components identified. However, most measures have used EPA analysis method TO 15, which typically only reports compounds identified of five carbons or more, such as the BTEX compounds of benzene, toluene, ethylbenzene and xylene. In the case of shale gas, the emissions also involve compounds in the one to three carbon range. Moreover, the compounds are frequently halogenated of short chain compounds in the mixtures.

Methylene chloride, a frequently identified shale gas compound, also has available research on the health effects of acute exposures. Methylene chloride is therefore used to characterize the contribution of C1-C5 halogenated VOCs to the acute toxicity of the mixture.

$PM_{2.5}$, an easily inhaled air pollutant, interacts with VOCs and thus increases contaminant transport to the deep lung in a way that multiplies the exposure and toxic actions. Therefore, a synergistic action is considered in the analysis. The 10-fold level of synergism (greater than additive effect) is used in this analysis, lowering the reference values (other than $PM_{2.5}$) by a factor of 10.

Table D shows current OSHA reference values for the five compounds of interest, the health systems affected, and the estimated amounts of each compound at median and 90th percentile levels of exposure. Table E shows OSHA reference levels for VOCs of interest in chemical classes of the mixture. Tables F and G show the newly factored (tenfold) reference levels, the modeled exposure levels for the five compounds, and whether the exposure levels exceed the adjusted reference levels.

Table D. OSHA guidance values and relative amounts of 5 compounds in shale gas emissions and health systems affected.

Compound	OSHA GUIDANCE mg/m^3	Percent of compounds in mixture	Median hourly air level of mixture 10,000ug/m^3	90th % hourly air level of mixture 30,000ug/m^3	Actions affect Systems***
NO_x	1.8	40%	4,000 (4.0mg)	12,000 (12.0 mg)	R. S
CO^	40	30%	3,000 (3.0mg)	9,000 (9.0mg)	N, C.
VOCs*	2/ 438	12%	1,200 (1.2mg)	3,600 (3.6mg)	R,S,N,C
$PM_{2.5}$**	15 µg/m3	3%	300 (0.3 mg)	900 (0.9 mg)	R. C.
Formaldehyde	0.035	3%	300 (0.3 mg)	900 (0.9 mg)	R.
Others	NA	12%	--------	-------	-------

*VOCs Based on methylene chloride OSHA short term exposure limit (STEL)
** $PM_{2.5}$ based on EPA AQI
*** R= upper and lower respiratory system; S=sensory systems, eyes nose throat, C= cardiovascular system; N= neurological system including headache; difficulty concentrating or confusion.
^Carbon monoxide at 40 mg/m^3 one hour exposure induces 2.5% carboxyhemoglobin.

Table E. OSHA guidance for reference VOCs based on chemical classes in the mixture.

Chemical Class	Reference Chemical	OSHA Guidance level *mg/m³*
PAH	Naphthalene	50
Aromatic	Benzene	3.15
Alkanes	Hexane	180
Halo-alkanes	Di-chloroethane	790
C1 to C5	Propane	180
C1 to C5 halogens	Methylene Chloride	438.0 OSHA STEL*

** OSHA short term exposure limit (STEL) has a duration of 15 minutes.*

Selection of mixture reference levels: It is likely that residents who experience exposures near shale gas sources will vary in age, gender and health conditions. Work place standards are generally focused on healthy male workers. Therefore, the guidance levels should be adjusted for the general population.

The mixture contains $PM_{2.5}$ which increases transport into the lungs and absorption into the body 10-fold or more depending on the level of $PM_{2.5}$ and size of particulates.

Conditions where one or more reference values are exceeded in exposure to the mixture are shown the tables F and G below. The adjusted reference values at the median and 90^{th} percentile (peak) ambient air levels are depicted.

Table F. Median mixture of 10,000 µg/m³ showing exposure level relative to reference value.

Chemical	Under reference value	Adjusted Reference Value	Exceeds reference value	Over reference
NO_x	-----	1800	4000	Yes
CO	3000	4,000	-----	No
VOC*	1200	43,800	-----	No
$PM_{2.5}$	-----	15	300	Yes
Formaldehyde	-----	3.5	300	Yes
Other toxics	-----	NA	1200	Yes

**VOCs reference value is based on methylene chloride OSHA STEL, $PM_{2.5}$ based on EPA AQI*

Table G. 90th percentile mixture of 30,000 μg/m³ showing exposure level relative to reference value.

Chemical	Under reference value	Adjusted Reference Value	Exceeds reference value	Over reference
NO_x	-----	1800	12000	Yes
CO	-----	4,000	9000	Yes
VOC*	3600	43,800	-----	No
PM2.5	-----	15	-----	Yes
Formaldehyde	-----	3.5	-----	yes
Other toxics	-----	NA	-----	Yes

**VOCs Based on methylene chloride OSHA STEL, $PM_{2.5}$ based on EPA AQI*

Tables F and G show that one or more of the components of the mixture exceeds the EHP reference value for eliciting a health response in members of the exposed population after an exposure of one hour duration.

Fewer chemical concentrations exceed the OSHA reference value at mixture levels of 1000 μg/m³ or less as shown below in Table H.

Table H. Comparison of chemical exposure levels at different mixture values relative to OSHA reference values.

Weight of mixture μg/m³	NO_x μg/m³	CO μg/m³	VOCs* μg/m³	$PM_{2.5}$ μg/m³	Formaldehyde μg/m³
OSHA Reference values	**1800**	**4000**	**200**	**15**	**3.5**
1000	400 -	300-	120-	30+	30+
2500	1000 -	750-	300+	75+	75+
5000	2000 +	1500-	600+	150+	150+
10,000	4000 +	3000-	1200+	300+	300+
30,000	12,000 +	9000+	3600+	900+	900+

* *Accumulates in lipids- neuro-toxic actions*

Based on the above analysis, the following health risk guidance is presented:

Table 3. Exposure levels of the mixture (NO_x, CO, VOCs, Formaldehyde, PM) emitted from natural gas compressor stations that can elicit health symptoms. Levels reported in ($\mu g/m^3$)

Exposure	Air level	Possible symptoms experienced	Physical system affected
Low	less than 500 $\mu g/m^3$	Eye and throat irritation	Ears, eyes, nose and throat
Moderate	500 to 1000 $\mu g/m^3$	Eye and throat irritation, headache	Ears, eyes, nose and throat; neurological
High	1000 to 2500 $\mu g/m^3$	Eye and throat irritation, headache, shortness of breath, palpitations, chest pain, changes in blood pressure and/or heart rate	Ears, eyes, nose and throat; neurological, respiratory, cardiovascular
Extreme	2500 to 5000 $\mu g/m^3$ and above	Eye, nose, throat irritation, headache, shortness of breath, palpitations, chest pain, changes in blood pressure and/or heart rate, impaired cognitive function such as confusion and difficulty concentrating	Ears, eyes, nose and throat; neurological, respiratory, and worsening cardiovascular effects

Discussion

This report is an analysis of the potential relationships between the amount of mixtures in ambient air and the symptoms expected. While there are limitations to the assumptions in the analysis they are based on "probable case", not on "worst case", assumptions.

Symptoms in residents exposed to emissions from shale gas facilities have been reported in peer-reviewed literature. The industry is required to report emissions to an inventory for each shale gas source in Pennsylvania.[28] Wells and other facilities are located in residential areas such that multiple facilities may be present. The ambient air

[28] Pennsylvania Department of Environmental Protection
https://www.dep.pa.gov/DataandTools/Reports/Pages/Air-Quality-Reports.aspx

concentrations at any given time are determined by emission rates from all the facilities and dilution by local weather conditions. The symptoms reported by local residents are said to "come and go," and "usually at night or early morning." State enforcement monitoring is based on investigator observations, often during the day after complaints have been filed by residents. It is unlikely that this follow-up monitoring can detect exposures under different emission and weather conditions.

Estimates of hourly air levels based on the annual hourly reports of metrological conditions have been conducted to determine the scope and maximal intensity of the potential exposures.

Limitations of risk guidance analysis:

1. The air emission values used are reported in tons per year for each chemical and extrapolated to grams/hour based on the assumption that emissions are uniform over the year. This assumption would over-estimate the lower daily emissions and under- estimate the actual higher daily emissions. Thus, the maximum values in the report are conservative.
2. Except for $PM_{2.5}$, it is assumed that each chemical's physiological action is independent of the other chemicals in the mixture.
3. VOC reference numbers are based on the assumption that all components have the same potency as methylene chloride and that the EPA guideline is a threshold assumption.
4. Weather dilution is assumed to follow the guidance in Pasqual's original report[29]. The assumption would not apply to "streaming plumes" sometimes experienced in wind conditions over 5 to 10 miles per hour.
5. Additional compounds are in the mixture. Those compounds are assumed to not have any impact on the health reports from residents.
6. Chronic health effects are not considered.
7. It is assumed that each hourly exposure is independent of the exposures in previous hours, given that the time between peak exposures is estimated at 3 hours or more. For carbon monoxide that assumption is not acceptable, due to its biological half-life in excess of three hours.

Conclusions

1. This analysis demonstrates that reference guidelines and standards can be used to estimate health risk levels for mixtures of compounds.
2. Symptom reports related to the respiratory, nervous and cardiovascular systems would be expected at hourly ambient air levels of this mixture in the 500 to 10,000 $\mu g/m^3$ range.
3. Levels of 1000 to 2500 $\mu g/m^3$ could be considered a threshold for induction of acute effects for this mixture of emissions.

[29] Pasquill, F. Atmospheric Diffusion: The Dispersion of Windborne Material from Industrial and other Sources.: D. Van Norstand Company, Ltd: London, 1962.