David O. Carpenter*

Hydraulic fracturing for natural gas: impact on health and environment

DOI 10.1515/reveh-2015-0055
Received October 16, 2015; accepted December 14, 2015; previously published online March 4, 2016

Abstract: Shale deposits exist in many parts of the world and contain relatively large amounts of natural gas and oil. Recent technological developments in the process of horizontal hydraulic fracturing (hydrofracturing or fracking) have suddenly made it economically feasible to extract natural gas from shale. While natural gas is a much cleaner burning fuel than coal, there are a number of significant threats to human health from the extraction process as currently practiced. There are immediate threats to health resulting from air pollution from volatile organic compounds, which contain carcinogens such as benzene and ethyl-benzene, and which have adverse neurologic and respiratory effects. Hydrogen sulfide, a component of natural gas, is a potent neuro- and respiratory toxin. In addition, levels of formaldehyde are elevated around fracking sites due to truck traffic and conversion of methane to formaldehyde by sunlight. There are major concerns about water contamination because the chemicals used can get into both ground and surface water. Much of the produced water (up to 40% of what is injected) comes back out of the gas well with significant radioactivity because radium in subsurface rock is relatively water soluble. There are significant long-term threats beyond cancer, including exacerbation of climate change due to the release of methane into the atmosphere, and increased earthquake activity due to disruption of subsurface tectonic plates. While fracking for natural gas has significant economic benefits, and while natural gas is theoretically a better fossil fuel as compared to coal and oil, current fracking practices pose significant adverse health effects to workers and near-by residents. The health of the public should not be compromized simply for the economic benefits to the industry.

Keywords: benzene; cancer; fracking; methane; respiratory diseases; shale.

***Corresponding author: David O. Carpenter,** MD, Institute for Health and the Environment, University at Albany, Rensselaer, NY 12144, USA, E-mail: dcarpenter@albany.edu

Introduction

Shale deposits around the earth contain significant reservoirs of natural gas and oil. Until recently these deposits were not economically accessible, but recent advances in the development of the process of horizontal hydrofracturing, or "fracking", of the shale formations have allowed recovery of natural gas in a cost-effective fashion. This method has also been referred to as "unconventional oil and gas extraction". The application of these procedures has occurred especially in North America and Australia, but almost certainly will be applied throughout much of the world in the future. It has been suggested that the new largest developments will occur in China, India, Indonesia and Poland, all of whom have significant shale reserves (1, 2).

Figure 1 shows the global distribution of shale deposits. The natural gas is contained within the shale deposits, which are often located at significant depths of several kilometers, much below the level of the water table. A borehole is drilled vertically into the shale area and then is drilled laterally. The well casing of steel pipe is installed, and the upper portion lined with concrete. Water at high pressure containing a variety of chemicals (often proprietary) and a propping agent (usually sand) is injected into the shale to break it apart and allow release of the gas. The general classes of chemicals include biocides such as glutaraldehyde, surfactants, friction reducers, electrolytes, breakers such as sodium chloride, corrosion inhibitors, iron control agents, oxygen scavengers, and scale inhibitors. The propping agents hold open the fractures, which may be up to 2.5 cm in length and normally extend several to hundreds of meters from the well casing. The amount of water required is significant. For 17,265 horizontal fracking sites in the US between 2000 and 2010 the average water used was 11,392 m^3/well, and the maximum was 42,372 m^3/well (3).

Health and environmental impacts

While the economic impacts of being able to access these natural gas deposits have already been considerable,

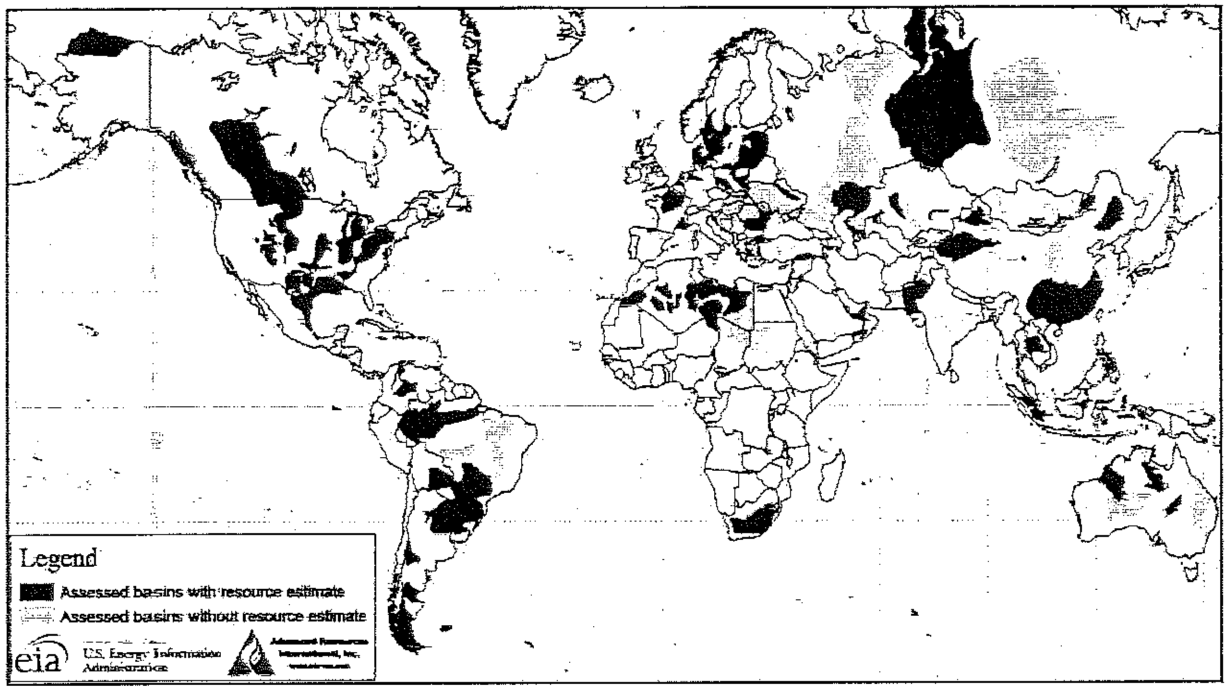

Figure 1: Map of basins with assessed shale oil and gas formations, as of May 2013.
From US Energy Information Administration and US Geological Survey (2).
Source: United States basins from U.S. Energy Information Administration and United States Geological Survey; other basins from ARI based on data from various published studies.

there are also a number of concerns about human health impacts, both long and short term. The amount of water used per well is enormous, and many wells in the US are in places where adequate water supply is already a concern. Furthermore, up to 40% of the injected water comes back as produced water, containing chemicals, unusually high salt concentrations from primeval deposits, and naturally-occurring radioactive materials. The disposal of the produced water is a major problem, as conventional waste-water treatment plants are usually not capable of removing the chemicals or radioactive compounds. Ground and surface water contamination has been reported (4, 5) resulting from transportation spills, well casing leaks, leaks through the fractured rock, and wastewater disposal. Methane contamination of drinking water is a concern (6). In some places there was sufficient methane in household drinking water such that water from the kitchen sick could be lit by a flame. Depending upon the nature of the rock formations, the flow-back water may contain significant levels of radium. Radium, unlike uranium or thorium, is relatively water soluble, and the two principal isotopes have half-lives of 1600 and 5.75 years. In the Marcellus shale in Eastern United States the produced water had a median radium activity 2460 pCi/L, which is extremely high compared with the drinking water limit of 5 pCi/L and the limit for industrial effluent of 60 pCi/L (7). Because the produced water contains high salt concentrations there have been occasions where it was spread on roads for ice control in the winter without anyone monitoring levels of radioactivity. Since radium decays to radon gas, which has a half-life of 3.8 days, there is also some concern about levels of radon in natural gas. Radon radioactivity measured in natural gas samples obtained from 11 wells in Pennsylvania ranged from 1 to 79 pCi/L (8).

One solution for dealing with produced water has been to inject it deep into the earth. This, however, has resulted in a sharp increase in earthquakes (9). Fortunately to date none have been large, but the frequency with which they occur in areas with deep injection indicates potential danger.

In addition to concerns about surface and groundwater contamination with chemical and radioactive materials, there are major concerns about air pollution (10). Natural gas is primarily methane, but also contains other volatile organic compounds, aromatics, CO_2, H_2S and SO_2 (11). There is often significant release of natural gas from well sites and compressor stations. My colleagues

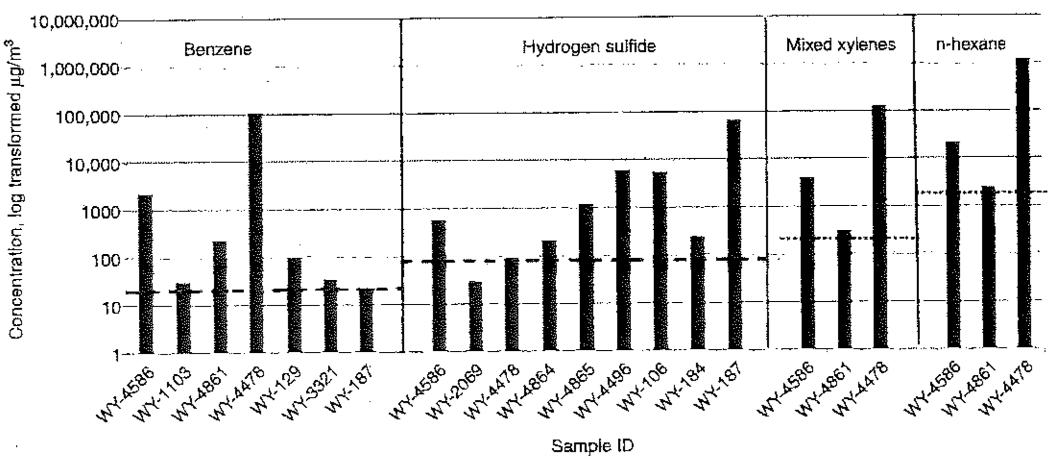

Figure 2: Concentrations of volatile compounds exceeding health-based risk levels in samples collected in Wyoming.
Note log scale on y-axis. Dashed lines represent ATSDR intermediate-term MRLs. Dotted lines represent ATSDR chronic MRLs (not displayed: toluene, ethylbenzene, and formaldehyde). From Macey et al. (12).

and I have reported on levels of volatile organic pollutants including benzene, hexane, formaldehyde, and H_2S around fracking sites in six US states (12). When compared to cancer and non-cancer federal exposure standards, we found that 40% of the samples we collected exceeded safe levels. Figure 2 shows results from samples obtained in Wyoming in relation to the minimal risk levels (MRL) set by ATSDR for benzene, H_2S, mixed xylenes and n-hexane. All these pollutants harm the respiratory and nervous systems and of particular concern is benzene, a known human carcinogen. Figures 3 and 4 show results for concentrations of formaldehyde and 1,3-butadiene in samples from Arkansas and Pennsylvania in relation to the USEPA IRIS 1/10,000 risk level, respectively. With the exception of formaldehyde, which was collected on a badge for an exposure period of at least 8 h, all other air samples were collected at points in time when there was an odor or some other reason to expect elevated concentrations of contaminants. These may be worst case scenarios, but clearly indicate potential hazards to human health. The elevations in levels of formaldehyde were striking. Formaldehyde is also a known human carcinogen. It is not certain that formaldehyde is a component of natural gas, but it is formed both from combustion (flaring of natural gas, exhaust from diesel trucks) and by action of sunlight on methane.

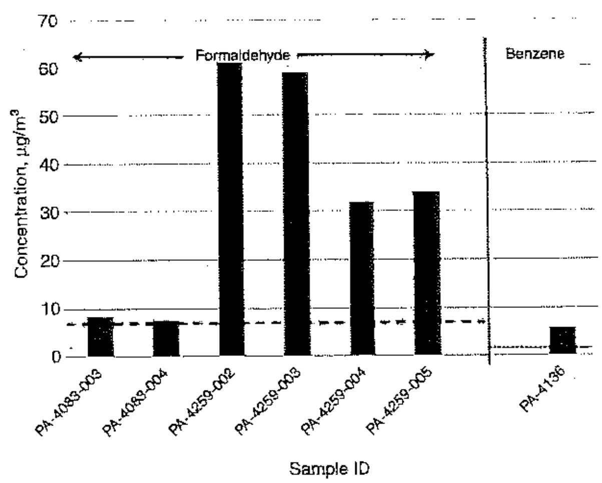

Figure 4: Concentrations of volatile compounds exceeding health-based risk levels in samples collected in Pennsylvania.
Dashed line represents EPA IRIS 1/10,000 cancer risk for formaldehyde. Dotted line represents EPA IRIS 1/100,000 cancer risk for benzene. From Macey et al. (12).

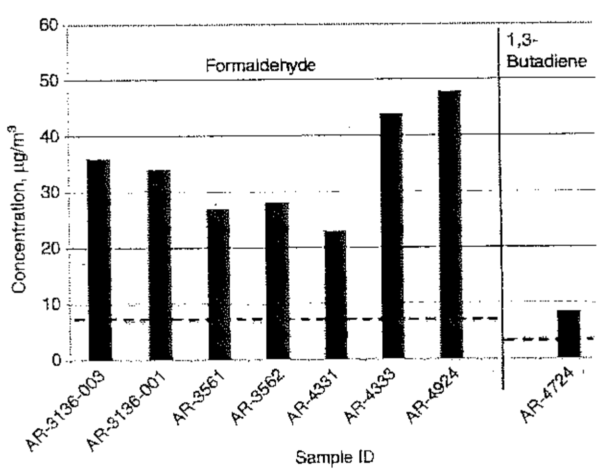

Figure 3: Concentrations of volatile compounds exceeding health-based risk levels in samples collected in Arkansas.
Dashed lines represent EPA IRIS 1/10,000 cancer risk for formaldehyde and 1,3 butadiene. From Macey et al. (12).

Others have measured polyaromatic hydrocarbons (PAHs) in particulates and found high concentrations around well sites (13). PAHs are also known human carcinogens. Because cancer has a long latency the presence of so many known carcinogens in the air around fracking sites is of great concern.

Colborn et al. (14) examined 632 chemicals known to be used during natural gas extraction, and noted that many of these chemicals have known effects on skin, eyes, nervous, respiratory, gastrointestinal and cardiovascular systems. McKenzie et al. (15) observed elevations in rates of congenital heart disease and possibly neural tube defects in children born to mothers living within 10 miles of natural gas wells. There is strong evidence that air pollution increases risk of asthma (16) and cardiovascular disease (17). Inhalation of volatile organics is known to result in central nervous system alterations (18). The health of farm and pet animals is also a concern at sites near to the fracking wells (19). While there are few peer-reviewed reports of symptoms experienced by residents living near to fracking sites, advocacy groups have documented elevations in respiratory symptoms, behavior/mood and energy changes, and nosebleeds (20, 21).

A major long-term concern is determining the net benefit or harm from the process of fracking and burning natural gas as compared to that from extraction and use of alternative fossil fuels. Howarth (22) has presented data in support of the view that the greenhouse footprint of shale gas is even worse than that of coal, primarily because of methane releases, although the analysis of Hultman et al. (23) concluded that the greenhouse gas impacts of unconventional natural gas extraction and use was only 56% of that of coal. Methane is actually a more potent greenhouse gas than carbon dioxide, although it has a shorter half-life in the atmosphere (24). The industry should be able to find ways to reduce the unintended release of methane, but it will never go to zero. Climate change is a global concern, and these different conclusions indicate that further study is necessary. Obviously the ultimate goal should be to ween all of us away from use of fossil fuels.

In theory combustion of natural gas should be preferable to combustion of coal because it produces less CO_2. But any advantage is offset by releases of methane to the atmosphere as well as local releases of methane along with other VOCs, H_2S, particulate air pollution and formaldehyde. The short term health effects of fracking will be primarily on workers and near-by residents who are exposed to air and water contaminants, radioactivity and excessive noise and light pollution. These exposures will results in respiratory symptoms, neurologic impairment from the H_2S and volatile organic compounds, and stress resulting from the smells, dusts, noise and light pollution. Esswein et al. (25) have also reported worker exposure to respirable crystalline silica that can result in restrictive lung disease. Furthermore, there are long-term dangers not only from cancer occurring in near-by residents and workers, but also from increased release of greenhouse gasses, excessive use of water and even generation of earthquakes. Fracking that is done in a responsible fashion may be of benefit, but present practices pose significant hazards to health and the environment.

References

1. Peduzzi P, Harding R. Gas fracking: can we safely squeeze the rocks? Environ Develop 2013;6:86–99.
2. United States Energy Information Administration. Technically recoverable shale oil and shale gas resources: an assessment of 137 shale formations in 41 countries outside the United States. Available at: http://www.eia.gov/analysis/studies/worldshalegas/.
3. Gallegos TJ, Varela BA. Trends in hydraulic fracturing distributions and treatment fluids, additives, proppants, and water volumes applied to wells drilled in the United States from 1947 through 2010: data analysis and comparison to the literature (USGS Numbered Series No. 2014-5131), Scientific Investigations Report. U.S. Geological Survey, Reston, VA 2015.
4. Rozell DJ, Reaven SJ. Water pollution risk associated with natural gas extraction from the Marcellus Shale. Risk Anal 2012;32:1382–93.
5. Warner NR, Christie CA, Jackson RB, Vengosh A. Impacts of shale gas wastewater disposal on water quality in western Pennsylvania. Environ Sci Technol 2014;47:11849–57.
6. Osborn SG, Vengosh A, Warner NR, Jackson RB. Methane contamination of drinking water accompanying gas-well drilling and hydraulic fracturing. Proc Natl Acad Sci 2011;108:8172–6.
7. Rowan EL, Engle MA, Kirby CS, Kraemer TF. Radium content of oil- and gas-field produced waters in the northern Appalachian Basin (USA) – Summary and discussion of data. U.S. Geological Survey Scientific Investigations Report 2011-5135 2011. Available at: http://pubs.usgs.gov/sir/2011/5135/.
8. Rowan EL, Kraemer TF. Radon-222 content of natural gas samples from upper and middle devonian sandstone and shale reservoirs in Pennsylvania: preliminary dat. U.S. Geological Survey Open-File Report 2012–1159 2012. Available at: http://pubs.usgs.gov/of/2012/1159.
9. Keranen KM, Weingarten M, Abers GA, Bekins BA, Ge S. Sharp increase in central Oklahoma seismicity since 2008 induced by massive wastewater injection. Science 2014;345:448–51.
10. Field RA, Soltis J, Murphy S. Air quality concerns of unconventional oil and natural gas production. Environ Sci Process Impacts 2014;16:954–69.
11. Gilman JB, Lerner BM, Kuster WC, de Gouw JA. Source signature of volatile organic compounds from oil and natural gas operations in northeastern Colorado. Environ Sci Technol 2013;47:1297–305.

12. Macey GP, Breech R, Chernaik M, Cox C, Larson D, et al. Air concentrations of volatile compounds near oil and gas production: a community-based exploratory study. Environ Health 2014;13:82.
13. Paulik LB, Donald CE, Smith BW, Tidwell LG, Hobbie KA, et al. Impact of natural gas extraction on PAH levels in ambient air. Environ Sci Technol 2015;49:5203–10.
14. Colborn T, Kwiatkowski C, Schultz K, Bachran M. Natural gas operations from a public health perspective. Human Ecol Risk Assess 2011;17:1039–56.
15. McKenzie LM, Guo R, Witter RZ, Savitz DA, Newman LS, et al. Birth outcomes and maternal residential proximity to natural gas development in rural Colorado. Environ Health Perspect 2014;122:412–7.
16. Samoli E, Nastos PT, Paliatsos AG, Katsouyanni K, Priftis KN. Acute effects of air pollution on pediatric asthma exacerbation: evidence of association and effect modification. Environ Red 2011;111:418–24.
17. Brook RD, Rajagopalan S, Pope A III, Brook JR, Bhatnagar A, et al. Particulate matter air pollution and cardiovascular disease: an update to the scientific statement from the American Heart Association. Circulation 2010;121:2331–78.
18. Verberk MM, van der Hoek JAF, van Valen E, Wekking EM, van Hout MSE, et al. Decision rules for assessment of chronic solvent-induced encephalopathy: results in 2370 patients. NeuroToxicol 2012;33:742–2.
19. Bamberger M, Oswald RE. Unconventional oil and gas extraction and animal health. Environ Sci Process Impact 2014;16:1860–5.
20. Earthworks. Gas patch roulette: how shale gas development risks public health in Pennsylvania. Available at: https://www.earthworksaction.org/files/publications/Health-Report-Full-FINAL-sm.pdf.
21. Center for Environmental Health. Toxic and dirty secrets: the truth about fracking and your family's health. Available at: http://www.ceh.org/legacy/storage/documents/Fracking/fracking_final-low-1.pdf.
22. Howarth RW. A bridge to nowhere: methane emissions and the greenhouse gas footprint of natural gas. Energy Sci Eng 2014;2:47–60.
23. Hultman N, Rebois D, Scholten M, Ramig C. The greenhouse impact of unconventional gas for electricity generation. Environ Res Lett 2011;6:049504.
24. Alvarez RA, Pacala SW, Winebrake JJ, Chameides WL, Hamburg SP. Greater focus needed on methane leakage from natural gas infrastructure. Proc Natl Acad Sci 2012;109:6435–40.
25. Esswein EJ, Breitenstein M, Snawder J, Kiefer M, Sieber WK. Occupational exposures to respirable crystalline silica during hydraulic fracturing. J Occup Environ Hyg 2013;10(7):347–56.