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FUGITIVE EMISSIONS FROM HYDRAULIC FRACTURING: CURRENT KNOWLEDGE AND POLICY IMPLICATIONS

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ABSTRACT

In recent years, the media has given significant attention to alarmist reports that fugitive emissions that stem from hydraulic fracturing produce vast amounts of greenhouse gases, despite repeated confirmation that such reports are based on faulty data. Meanwhile, recent U.S. Environmental Protection Agency (EPA) regulations result in the capture or control of approximately 95 percent of fugitive emissions from hydraulically fractured natural gas wells. The potential for so-called "fracking" either to accelerate climate change or to have negative effects on public health is similarly limited.

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INTRODUCTION

Recent innovations in drilling technology, especially staged hydraulic fracturing ("fracking")[1] and horizontal drilling,[2] have unlocked unconventional resources[3] of oil and natural gas. These developments represent a revolutionary moment in the energy industry, both in the United States and worldwide, as vast reserves[4] [5] of previously inaccessible oil and gas are now within reach.[6]

While these advancements carry the promise of a more prosperous future, there is considerable debate over the potential effects of so-called "fugitive emissions" from fracking operations. The primary concerns involve whether fugitive emissions will influence climate change or cause harmful health impacts. Based on a review of recent academic research, as well as government and industry reports, it appears the EPA regulations set in place in late 2012 should mitigate the vol-

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1. Hydraulic fracturing has been used in various forms since the 1940s, but the technology has been continually refined in order to stimulate additional production from oil and gas wells. See Montgomery, and M. B. Smith, "Hydraulic Fracturing: History of an Enduring Technology," *Journal of Petroleum Technology*, 62(12): 26-32, 2010. http://www.spe.org/jpt/print/archives/2010/12/10Hydraulic.pdf

2. Horizontal drilling allows a single drilling site to access much more subterranean resources than vertical drilling alone, by turning the well shaft to run horizontally through a layer of oil- or gas-bearing rock.

3. These resources are termed "unconventional" because the methods required to access them are different than those traditionally used in oil and gas extraction. "Conventional" oil and gas resources are contained in relatively porous rock formations where the oil and gas easily flow through the formation to the well shaft and then to the surface. Unconventional oil and gas resources are trapped in "tight" rock formations whose low permeability inhibits movement of the resources. Shale is one example of a tight formation where hydraulic fracturing can be used break the rock, extending cracks from the well shaft through the formation and allowing the oil and gas to flow to the well shaft and then to the surface.

4. Shale energy resources now constitute 10 percent of the world's oil resources and 32 percent of the world's gas resources. In the United States, newly accessible shale oil and gas resources increased total national resources by 35 percent and 38 percent, respectively. See U.S. Energy Information Agency, "World Shale Gas Resources: An Initial Assessment of 14 Regions Outside the United States," 2013. Retrieved from http://www.eia.gov/analysis/studies/worldshalegas/ (Accessed January 2014)

5. Increasing production from new tight oil resources is expected to result in the United States overtaking Saudi Arabia to become the world's largest producer of liquids in 2014. U.S. oil imports are expected to fall nearly 75 percent between 2012 and 2035; Shale gas supplies are expected to meet 46 percent of the growth in gas demand and account for 21 percent of world gas and 68 percent of U.S. gas production by 2035. See British Petroleum, "BP Energy Outlook 2035-Press Release," 2013. Retrieved from http://www.bp.com/en/global/corporate/press/press-releases/energy-outlook-2035.html. (Accessed January 2014).

6. The combination of these innovations allows for the economically feasible recovery of resources which previously were not profitable because the cost per well was higher than the value of the limited amount of oil or gas that could be extracted.

ume of fugitive emissions and that additional regulation is unnecessary. The review also suggests the following conclusions:

- Fugitive emissions could indeed increase the GHG footprint of the natural gas industry, but not as much as some recent alarmist reports.

- More importantly, fugitive emissions and natural gas facility leaks have been associated with harmful public health impacts.

- Rules set in place in late 2012 decrease fugitive emissions by 95 percent at each well,[7] making additional regulation of hydraulic fracturing at natural gas wells unnecessary.

FUGITIVE EMISSIONS OVERVIEW

Fugitive emissions from oil and gas wells are inadvertent releases of gases generally consisting of methane, volatile organic compounds (VOCs) and hazardous air pollutants (HAPs).[8] [9] Oil and gas wells that use hydraulic fracturing are most likely to produce fugitive emissions following the fracturing operation when a large volume of the drilling fluid mixed with hydrocarbons surges back to the surface. Prior to October 2012, this "flowback" was sometimes directly routed to an on-site retention basin, where the liquid would be captured while the gas component would be vented to the atmosphere.[10]

These emissions have caused considerable controversy in both academic and public policy circles. In 2011, a research team led by Cornell University professor Robert Howarth estimated that 3.6 percent to 7.9 percent of a shale well's total lifetime natural gas production escapes to the atmosphere through venting after fracking, as well as other leaks.[11] These findings indicate the GHG footprint of shale gas production was larger than that of coal mining – information that was widely reported in the news media.[12]

However, multiple subsequent academic studies [13] [14] [15] [16] and reports by industry,[17] think tank[18] and governmental[19] sources contradict Howarth's findings, with general agreement that his conclusions were based on unreliable or incorrect data. The consensus is now clear that the GHG footprint of shale gas used for electricity generation is about half of the GHG footprint of coal-based power.[20]

The most recent research supports the conclusion that fugitive emissions from hydraulically fractured gas wells are minimal. An in-depth study by David Allen at the University of Texas published recently in the *Proceedings of the National Academy of Sciences* examined methane output from natural gas drilling and hydraulic fracturing operations at various locations around the United States.[21] Allen found measurements of emissions taken at wells using hydraulic fracturing were substantially lower than estimates used by the EPA. However, Scot Miller of Harvard University found conflicting results when he examined data collected from sensors mounted on towers and planes.[22] His measurements found total atmospheric methane content that was 1.5 to 1.7 times larger than the estimates produced using standard EPA methodology.

One potential explanation for these divergent conclusions

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7. U.S. Environmental Protection Agency, "EPA's Air Rules for the Oil & Natural Gas Industry – Summary of Requirements for Processes and Equipment at Natural Gas Well Sites," 2012. Retrieved from http://www.epa.gov/airquality/oilandgas/pdfs/20120417summarywellsites.pdf. (Accessed January 2014).

8. U.S. Environmental Protection Agency, "Natural Gas STAR Program. Reduce Your Methane Emissions," Retrieved from http://www.epa.gov/gasstar/methaneemissions/index.html (Accessed January 2014)

9. Methane, the primary constituent of natural gas, is a potent greenhouse gas and is combustible in the proper concentrations. VOCs contribute to the formation of smog, which has been linked to a number of adverse health impacts. Exposure to HAPs has been associated with serious negative health effects and cancer. See U.S. Environmental Protection Agency, "Oil and Natural Gas Air Pollution Standards. Basic Information," Retrieved from http://www.epa.gov/airquality/oilandgas/basic.html (Accessed January 2014).

10. U.S. Environmental Protection Agency, "Reduced Emissions Completions for Hydraulically Fractured Natural Gas Wells," 2011. Retrieved from http://www.epa.gov/gasstar/documents/reduced_emissions_completions.pdf (Accessed January 2014).

11. Howarth, R. Santoro and A. Ingraffea, "Methane and the greenhouse-gas footprint of natural gas from shale formations," *Climatic Change*, 106(4): 679-690. 2011. http://link.springer.com/article/10.1007%2Fs10584-011-0061-5

12. R. S. Lichter, "The Media's Gas Problem," Oct. 18, 2011. Retrieved from http://stats.org/stories/2011/medias_gas_problem_oct6_11.html (Accessed January 2014).

13. L. M. Cathles, "Assessing the greenhouse impact of natural gas," *Geochemistry, Geophysics, Geosystems*, 13(6), 2011.

14. N. Hultman, D. Rebois, M. Scholten and C. Ramig, "The greenhouse impact of unconventional gas for electricity generation," *Environmental Resource Letters*, 6(3), 2011.

15. M. Jiang, W. M. Griffin, C. Hendrickson, P. Jaramillo, J. VanBriesen and A. Venkatesh, "Life cycle greenhouse gas emissions of Marcellus shale gas," *Environmental Resource Letters*, 6(3), 2011.

16. F. O'Sullivan and S. Paltsev, "Shale gas production: Potential versus actual greenhouse gas emissions," *Environmental Resource Letters*, 7(4), 2012.

17. IHS-CERA, "Mismeasuring Methane: Estimating Greenhouse Gas Emissions from Upstream Natural Gas Development," 2011. Retrieved from http://www.ihs.com/images/MisMeasuringMethane082311.pdf. (Accessed January 2014).

18. M. Levi, "Some Thoughts on the Howarth Shale Gas Paper," Council on Foreign Relations. April 15, 2011. Retrieved from http://blogs.cfr.org/levi/2011/04/15/some-thoughts-on-the-howarth-shale-gas-paper/. (Accessed January 2014).

19. National Energy Technology Laboratory, "Life Cycle Greenhouse Gas Analysis of Natural Gas Extraction and Delivery in the United States," 2011. Retrieved from http://netl.doe.gov/research/energy-analysis/publications/details?pub=eaa7f83c-ff41-4712-b53c-52b22a3afa29. (Accessed January 2014).

20. Ibid.

21. D.T. Allen, et al, "Measurements of methane emissions at natural gas production sites in the United States," *Proceedings of the National Academy of Sciences*, 110(44): 17768-17773, 2013. http://www.pnas.org/content/early/2013/09/10/1304880110.abstract

22. S.M. Miller, et al, "Anthropogenic emissions of methane in the United States," *Proceedings of the National Academy of Sciences*, 110(50): 20018-20022, 2013. http://www.pnas.org/content/110/50/20018.full

is the difference in time periods considered. Miller's data is from 2007 and 2008, slightly before the industry and EPA began realizing that fugitive emission volumes were much larger than originally thought.[23 24 25 26] This time period also coincided with the peak boom of hydraulic fracturing in the Barnett Shale,[27 28] where Miller found substantially higher methane concentrations.

Allen used more recent data from the latter half of 2012, by which time there was widespread adoption of technology to mitigate fugitive emissions due to October 2012 EPA regulations prohibiting the venting of gases from natural gas wells. Because these gases also represent potential revenue, the industry already was moving to capture them before the regulations were announced.[29 30] The differences between Miller and Allen's results may indicate that previous emission levels from hydraulic fracturing were higher than expected, but with proper practices and technology, fugitive emissions from fracking are negligible.

23. A.C. Revkin and C. Krauss, "Curbing Emissions by Sealing Gas Leaks," *New York Times*, Oct. 14, 2009. Retrieved from http://www.nytimes.com/2009/10/15/business/energy-environment/15degrees.html?_r=1&

24. A.C. Revkin, "New Study Finds US Has Greatly Underestimated Methane Emissions," New York Times, Nov. 25, 2013. Retrieved from http://dotearth.blogs.nytimes.com/2013/11/25/new-study-finds-u-s-has-underestimated-methane-levels-in-the-atmosphere/

25. Texas Commission on Environmental Quality, "Barnett Shale Formation Area Monitoring Projects," 2010. Retrieved from http://www.tceq.state.tx.us/assets/public/implementation/barnett_shale/2010.01.27-BarnettShaleMonitoringReport.pdf. (Accessed January 2014).

26. T. Fowler, "State boosts air quality efforts in N. Texas shale field," *Houston Chronicle*, Jan. 10, 2010. Retrieved from http://www.chron.com/default/article/State-boosts-air-quality-efforts-in-N-Texas-1612402.php

27. Note: The Barnett Shale was the first major drilling boom utilizing hydraulic fracturing with horizontal drilling. There may have been a substantial amount of "learning by doing," which could explain higher methane losses than contemporary drilling practices. The current trend in the oil and gas industry is oriented toward installing equipment to capture natural gas that otherwise would be lost to the atmosphere or flared.

28. The summer peak nitrous oxide and VOC emissions from shale gas wells, storage tanks and compressor stations in the Barnett Shale region were estimated to exceed total emissions from all vehicles in the Dallas-Fort Worth area. See A. Armendariz, "Emissions from Natural Gas Production in the Barnett Shale Area and Opportunities for Cost-Effective Improvements," 2009. Retrieved from http://www.edf.org/sites/default/files/9235_Barnett_Shale_Report.pdf. (Accessed January 2014).

29. "During the first phase <which started in Oct. 2012>, until January 2015, owners and operators must either flare their emissions or use emissions reduction technology called 'green completions.'" These technologies were already widely deployed at natural gas wells. US Environmental Protection Agency. (2012, April 6). News Release. Retrieved from http://yosemite.epa.gov/opa/admpress.nsf/d0cf6618525a9efb85257359003fb69d/c742df7944b37c50852579e400594f8f!OpenDocument. (Accessed January 2014).

30. "A. J. Krieger, town administrator in Erie, Colo., about 20 miles north of Denver, last year signed a voluntarily agreement with two energy companies to mandate the use of vapor recovery units - something that isn't a typical industry practice but is becoming more widespread. The units capture pollutants, including carcinogens, which can be vented into the air during fracking operations." Gold, R., and T. McGinty. (2013, Oct 26). The Rig Next Door: Energy Boom Puts Wells in America's Backyards. Wall Street Journal.

SIDEBAR: A FRACKING GLOSSARY

Hydraulic Fracturing (aka "Fracking") – A process used to stimulate oil and gas well production volumes. It may be used in existing wells whose production has declined or in newly drilled wells. It involves pumping high-pressure water, gel or other liquid substances to the oil- and gas-bearing rock deep underground, which opens cracks in the rock that allow the oil and gas to flow to the well. This innovation is important, in that the process allows the recovery of "unconventional" oil and gas reserves, which otherwise would be uneconomical to harvest. Hydraulic fracturing has been used in various forms since the 1940s, but the technology has been continually refined in order to stimulate additional production from oil and gas wells.

"Unconventional" vs "Conventional" Oil and Gas Resources – Conventional oil and gas resources are contained in relatively porous rock formations where the oil and gas easily flow through the formation to the well shaft and then to the surface. Unconventional oil and gas resources are trapped in "tight" rock formations whose low permeability inhibits movement of the resources. These resources are termed 'unconventional' because the methods required to access them are different than those traditionally used in oil and gas extraction. Shale is one example of a tight formation where hydraulic fracturing can be used to break the reservoir rock, extending cracks from the well shaft through the formation and allowing the oil and gas to flow to the well shaft and then to the surface.

Horizontal drilling – Horizontal drilling allows a single drilling site to access much more subterranean resources than vertical drilling. It accomplishes this by turning the well shaft to run horizontally through a layer of oil- or gas-bearing rock. Although this technique is more expensive than vertical drilling, it increases the amount of oil and gas resources that can be harvested from a single well.

Flowback – After a well has been hydraulically fractured, some of the liquid used in the fracturing process rushes back to the surface accompanied by hydrocarbons from the well. This "flowback" must be cleared out of the well to allow for optimal production, a process that can take from a few days to several weeks. Given the large volumes of liquid used in hydraulic fracturing, accommodating the flowback generally requires a nearby retention basin or many tanker trucks.

Fugitive emissions – Fugitive emissions are inadvertent releases of gases from industrial facilities, especially those having to do with the oil and gas industry. In the context of hydraulic fracturing, the gases released by the flowback while it is stored in the retention basin are considered fugitive emissions.

Flaring – When unusable methane or other gases are produced from industrial activities, a safe means for their disposal involves venting the gas through a flare that ignites them, thereby converting the potentially hazardous substances to safer compounds, such as carbon dioxide and water vapor, although some minor pollutants like sulfur dioxide and nitrous oxide can also be created. This is a common procedure for many facilities, ranging from wastewater treatment plants and garbage landfills to oil wells and refineries. With regard to hydraulic fracturing, it's possible to extract the methane contained in the flowback and send it to a flare for safe disposal.

Reduced Emission Completion (REC)/"green completions" technology – REC technology provides the means to capture hydrocarbon gases and liquids in the hydraulic fracturing flowback so that their value is not lost. The use of REC technology at a gas well is estimated to pay for itself in less than a year by providing extra salable hydrocarbons, meaning there is a market incentive for the oil and gas industry to employ the technology.

CLIMATE CHANGE CONCERNS

Methane has been a focus of concern due to its contribution to climate change. The gas contains more than 20 times the global warming potential per molecule of carbon dioxide,[31] though the total impact of all U.S. methane emissions is still far below that of total CO2 emissions.[32] However, new rules implemented in 2012 by the EPA require natural gas wells using hydraulic fracturing either to install Reduced Emissions Completion (REC) technology or flare off gas contained in the flowback fluid.[33] Both of these technologies allow only a trivial amount of methane to escape into the atmosphere from fracked wells, meaning that the GHG footprint of fugitive emissions from fracking should be approximately the same as conventional natural gas wells. Given current EPA regulations, the climate change potential attributable to fugitive gas emissions from hydraulic fracturing no longer should be an issue.

Emissions of natural gas from compressor stations and from the transmission/distribution network also have been implicated as contributing to climate change.[34 35] However, these emissions were factored into the 2011 National Energy Technology Laboratory (NETL) report that found shale gas-fired power plants generate 50 percent less GHG per megawatt-hour than conventional coal-fired power plants.[36] Additionally, the EPA has set rules limiting emissions from natural gas facilities. Based on the regulatory changes since 2012, the potential impact on climate change of fugitive emissions and natural gas leakage should be reduced significantly.

PUBLIC HEALTH CONCERNS

Critics of hydraulic fracturing also argue that fugitive emissions from fracking are associated with negative health impacts. This issue has been the subject of numerous studies by governmental, industry and academic researchers, but the results are, at best, contradictory and offer no firm conclusions one way or the other.

The town of DISH, Texas provides a good example of these conflicting findings. A private environmental consulting firm found evidence of "carcinogenic and neurotoxin compounds" near shale wells and compressor stations.[37] The Texas Commission on Environmental Quality (TCEQ) reported that if the testing conducted by the consulting firm was accurate, it showed there were sufficient levels of odor-causing compounds to cause discomfort (headaches or nausea), but they were not high enough to create a toxic reaction if the exposure was short-term (one hour).[38] A subsequent study by the Texas Department of State Health Services (TxDSHS) found no evidence to suspect DISH residents had suffered community-wide exposure to VOCs.[39] However, an extended investigation by the TCEQ indicated there were isolated incidents throughout the Barnett Shale region where natural gas wells or compressor stations suffered gas leaks that caused levels of some chemicals, including benzene, to rise above recommended long-term exposure limits.[40]

The Pennsylvania Department of Environmental Protection (PA DEP) also carried out air sampling tests near shale gas wells, gas compressors and storage tanks in various parts of the state[41 42 43] Each report found fugitive emissions present near shale gas wells and gas processing equipment, although not at hazardous levels. However, the Pennsylvania DEP did

31. U.S. Environmental Protection Agency, "Oil and Natural Gas Air Pollution Standards. Basic Information," Retrieved from http://www.epa.gov/airquality/oilandgas/basic.html (Accessed January 2014).

32. The EPA estimated U.S. methane emissions in 2011 were 9 percent of total GHG emissions, compared to 84 percent for carbon dioxide (as compared on a CO_2-equivalent basis). See U.S. Environmental Protection Agency, "Overview of Greenhouse Gases," Retrieved from http://www.epa.gov/climatechange/ghgemissions/gases.html (Accessed January 2014).

33. U.S. Environmental Protection Agency, "Oil and Natural Gas Sector: New Source Performance Standards and National Emission Standards for Hazardous Air Pollutants Reviews," Aug. 16, 2012. Retrieved from http://www.gpo.gov/fdsys/pkg/FR-2012-08-16/pdf/2012-16806.pdf. (Accessed January 2014).

34. U.S. Environmental Protection Agency, "Oil and Natural Gas Air Pollution Standards. Basic Information," Retrieved from http://www.epa.gov/airquality/oilandgas/basic.html (Accessed January 2014).

35. A 2014 study by Jackson, et al, indicated there were more than 5,800 leaks in the natural gas distribution network in Washington, D.C. See R.B. Jackson, et al, "Natural Gas Pipeline Leaks Across Washington, D.C.," *Environmental Science & Technology*, 2014. http://pubs.acs.org/doi/abs/10.1021/es404474x

36. National Energy Technology Laboratory, "Life Cycle Greenhouse Gas Analysis of Natural Gas Extraction and Delivery in the United States," 2011 Retrieved from http://netl.doe.gov/research/energy-analysis/publications/details?pub=eaa7f83c-ff41-4712-b53c-52b22a3afa29. (Accessed January 2014).

37. Wolf Eagle Environmental, "Town of DISH, Texas Ambient Air Monitoring Analysis – Final Report," 2009. Retrieved from http://townofdish.com/objects/DISH_-_final_report_revised.pdf. (Accessed January 2014).

38. Texas Commission on Environmental Quality, "Interoffice Memorandum," Oct. 27, 2009. Retrieved from http://www.barnettshalenews.com/documents/ntxairstudy/Wolf percent20Eagle percent20Report percent20 percent20Evaluation percent20for percent20DISH percent20TX percent20by percent20TCEQ percent2010-27-2009.pdf. (Accessed February 2014).

39. Note: The blood and urine testing methodology employed by the Texas Department of State Health Services would have been able to determine only whether the DISH, Texas residents had been exposed to VOCs within the previous few hours. The Texas Department of Environmental Quality (TCEQ) did determine the short-term level of benzene (a hazardous air pollutant) exceeded TCEQ's long-term comparison value and recommended that subsequent long-term tests be carried out. See Texas Department of State Health Services, "Final Report – DISH, Texas Exposure Investigation," 2010. Retrieved from http://www.dshs.state.tx.us/epitox/consults/dish_ei_2010.pdf. (Accessed January 2014).

40. Texas Commission on Environmental Quality, "Barnett Shale Formation Area Monitoring Projects," 2010. Retrieved from http://www.tceq.state.tx.us/assets/public/implementation/barnett_shale/2010.01.27-BarnettShaleMonitoringReport.pdf. (Accessed January 2014).

41. Commonwealth of Pennsylvania Department of Environmental Protection, Bureau of Air Quality, "Southwestern Pennsylvania Marcellus Shale Short-Term Ambient Air Sampling Report," 2010. Retrieved from http://www.dep.state.pa.us/dep/deputate/airwaste/aq/aqm/docs/Marcellus_SW_11-01-10.pdf. (Accessed January 2014).

42. Commonwealth of Pennsylvania Department of Environmental Protection, Bureau of Air Quality, "Northeastern Pennsylvania Marcellus Shale Short-Term Ambient Air Sampling Report," 2011. Retrieved from http://www.dep.state.pa.us/dep/deputate/airwaste/aq/aqm/docs/Marcellus_NE_01-12-11.pdf. (Accessed January 2014).

43. Commonwealth of Pennsylvania Department of Environmental Protection, Bureau of Air Quality, "Northcentral Pennsylvania Marcellus Shale Short-Term Ambient Air Sampling Report," 2011. Retrieved from http://www.dep.state.pa.us/dep/deputate/airwaste/aq/aqm/docs/Marcellus_NC_05-06-11.pdf. (Accessed January 2014).

find methyl mercaptan concentrations strong enough for bothersome odors, which potentially could violate DEP provisions governing the emission of malodors (odors which could cause nausea or headaches).

Two studies investigating infant health in Colorado[44] and Pennsylvania[45] have identified a link between drilling activities and adverse health outcomes. The proximity of an expectant mother's home to hydraulically fractured oil and gas wells (within one mile) was significantly correlated with lower birth weight and gestational length. It is undetermined whether these health outcomes were influenced by fugitive emissions, well construction activities or some other effect that caused maternal stress, but this result parallels previous research findings that exposure to benzene[46][47] and other pollutants[48] reduces infant birth weight.[49]

Aside from empirical studies examining infant health, there is little concrete evidence linking hydraulic fracturing of oil and gas wells to adverse health outcomes. One reason for this may be the limited time period available for study. Alternatively, the effects of fugitive emissions might be noticeable only in certain situations, such as in developing children. Regardless, the new EPA regulations concerning fugitive emissions and natural gas leaks are likely to substantially reduce the potential for natural gas wells to have an impact on human health.

The recent regulatory changes do not eliminate the need for careful monitoring. The widespread availability of shale resources and the limited area from which any single well site can draw likely will combine to increase substantially the interaction between human activity and oil and gas extraction. A good example can be found in Johnson County, Texas, a suburb of Fort Worth with a population of roughly 150,000. In the year 2000, before the drilling boom in the Barnett Shale, there were only 20 oil and gas wells in the county. By year-end 2013, there were more than 3,900 wells, and nearly every county resident lived within one mile of a gas well.[50] This pattern is likely to repeat in many regions across the United States over the coming decades, as more shale gas and oil formations are discovered and exploited.

POLICY FRAMEWORK AND RECOMMENDATIONS

Any policies to govern fugitive emissions from hydraulic fracturing must be founded on a factual understanding of how emissions occur, their specific effects and the property rights of persons involved. If quantifiable negative effects associated with fugitive emissions are found, the cost of mitigating these impacts should be included in the production of gas and oil.

A full understanding of the short- and long-term effects of fugitive emissions is not yet available, nor is a complete accounting of how emission volumes vary based upon environmental conditions and the equipment used. Despite this lack of knowledge, there is sufficient evidence to conclude the effects of fugitive emissions might be non-negligible and that these effects may impact many lives over a large geographical area due to the widespread nature of shale resources. The impact of fugitive emissions on public health seems to be a more immediate and pressing issue than their potential for climate change, as the possible damage from climate change attributable to a given volume of fugitive emissions is small relative to their potential health impact.

Because fugitive emissions from wells, storage tanks, compressor stations, and other facilities have been widely documented,[51] the appropriate action would be either to require owners of these facilities to prove that such emissions are not harmful to human activities or to install equipment to restrict emissions to a volume demonstrated to be harmless. In fact, the latter largely already has been accomplished through EPA regulations[52] on hydraulic fracturing operations[53] that became effective in October 2012. Both of the methods the EPA sanctions to reduce emissions – REC technology and flaring off of natural gas – eliminate effectively the vast majority of fugitive emissions associated with hydraulic fracturing. The EPA also has instituted regulations

44. Elaine Hill, "The Impact of Oil and Gas Extraction on Infant Health in Colorado. Working paper," 2013. Retrieved from https://sites.google.com/site/elainelhill/. (Accessed January 2014).

45. Elaine Hill, "Shale Gas Development and Infant Health: Evidence from Pennsylvania. Working paper," 2013. Retrieved from https://sites.google.com/site/elainelhill/. (Accessed January 2014).

46. S. Zahran, S. Weiler, H.W. Mielke and A. A. Pena, "Maternal benzene exposure and low birth weight risk in the United States: A natural experiment in gasoline reformulation," *Environmental Research*, 112:139-146, 2012.

47. R. Slama, O. Thiebaugeorges, V. Goua, L. Aussel, P. Sacco, A. Bohet, et al, "Maternal personal exposure to airborne benzene and intrauterine growth," *Environmental Health Perspectives*, 117(8), 2009.

48. K.P. Stillerman, D.R. Mattison, L.C. Giudice and T.J. Woodruff, "Environmental exposures and adverse pregnancy outcomes: A review of the science," *Reproductive Sciences*, 15(7): 631-650, 2008.

49. See Hill, "The Impact of Oil and Gas Extraction on Infant Health in Colorado" and Stillerman, et al., "Environmental Exposures and Adverse Pregnancy Outcomes: A Review of the Science" for extended reviews of the relevant literature.

50. Gold, R., and T. McGinty. (2013, Oct 26). The Rig Next Door: Energy Boom Puts Wells in America's Backyards. Wall Street Journal.

51. Texas Commission on Environmental Quality, "Barnett Shale Formation Area Monitoring Projects," 2010. Retrieved from http://www.tceq.state.tx.us/assets/public/implementation/barnett_shale/2010.01.27-BarnettShaleMonitoringReport.pdf. (Accessed January 2014).

52. U.S. Environmental Protection Agency, "Oil and Natural Gas Air Pollution Standards – Regulatory Actions," 2012. Retrieved from http://www.epa.gov/airquality/oilandgas/actions.html. (Accessed January 2014).

53. U.S. Environmental Protection Agency, "EPA's Air Rules for the Oil & Natural Gas Industry – Summary of Requirements for Processes and Equipment at Natural Gas Well Sites," 2012. Retrieved from http://www.epa.gov/airquality/oilandgas/pdfs/20120417summarywellsites.pdf. (Accessed January 2014).

to reduce substantially the VOCs and HAPs leaked by gathering stations,[54] storage tanks[55] and processing plants.[56]

EPA regulations appear sufficient to limit fugitive emissions from hydraulic fracturing and leaks from natural gas operations to a volume that will not cause negative public health outcomes. These regulations also reduce substantially the GHG footprint attributable to natural gas production and consumption. While additional research is required before these conclusions can be verified fully, the best available evidence suggests natural gas wells have reduced their emissions to levels that minimize potential climate and health impacts without creating undue or onerous burdens on the industry.

The EPA still is considering whether to enact regulations on natural gas compressors and pneumatic controllers, as well as oil produced from hydraulic fracturing operations.[57] [58] The agency currently is gathering information on these issues. If the EPA determines regulations to be justifiable, they must be structured so as not to give an advantage to one company, individual or enterprise over another - the rules must be focused solely on the primary goal of ending harmful emissions. The rules also should be sufficiently flexible that oil and gas companies can meet emission standards in innovative ways that do not stifle the production of new resources. Additionally, all regulations should be reviewed periodically to determine whether their existence is still required and whether they accomplish the goal of preventing harm to human life.

CONCLUSION

Based upon a thorough review of academic, industry and governmental research, it appears that fugitive emissions from hydraulic fracturing and leaks from natural gas facilities do have the potential to negatively affect human health and impact climate change. However, current EPA regulations require that natural gas wells and industry operations reduce emissions to an apparently negligible level. Therefore, additional regulations on hydraulic fracturing emissions do not appear to be justified.

ABOUT THE AUTHOR

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54. U.S. Environmental Protection Agency, "EPA's Air Rules for the Oil & Natural Gas Industry – Summary of Requirements for Processes and Equipment at Natural Gas Gathering and Boosting Stations," 2012. Retrieved from http://www.epa.gov/airquality/oilandgas/pdfs/20120417summaryboost.pdf. (Accessed January 2014).

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