Research and Policy Recommendations for Hydraulic Fracturing and Shale-Gas Extraction

by

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Introduction

The extraction of natural gas from shale formations is one of the fastest growing trends in American on-shore domestic oil and gas production.[1] The U.S. Energy Information Administration (EIA) estimates that the United States has 2,119 trillion cubic feet of recoverable natural gas, about 60% of which is "unconventional gas" stored in low permeability formations such as shale, coalbeds, and tight sands.[2]

Large-scale production of shale gas has become economically viable in the last decade attributable to advances in horizontal drilling and hydraulic fracturing (also called "hydro-fracturing" or "fracking").[3] Such advances have significantly improved the production of natural gas in numerous basins across the United States,[4] including the Barnett, Haynesville, Fayetteville, Woodford, Utica, and Marcellus shale formations (Figure 1). In 2009, 63 billion cubic meters of gas was produced from deep shale formations. In 2010, shale gas production doubled to 137.8 billion cubic meters,[5] and the EIA projects that by 2035 shale gas production will increase to 340 billion cubic meters per year, amounting to 47% of the projected gas production in the United States.

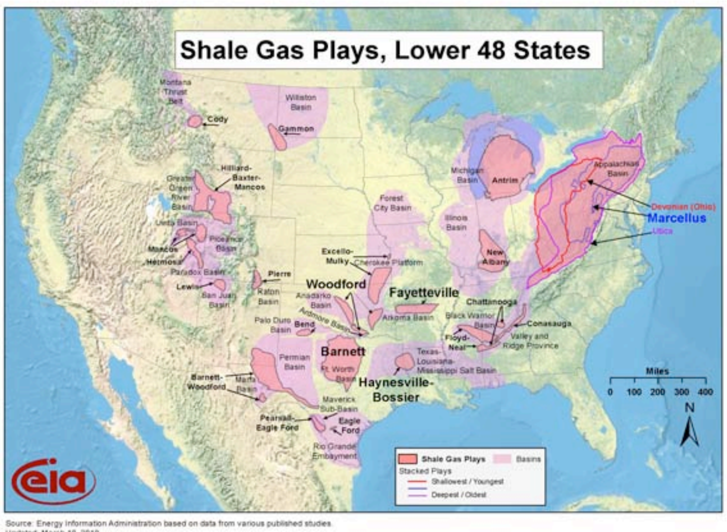

Figure 1: Map of the shale gas basins in the United States. Source: U.S. Energy Information Administration (EIA) http://www.eia.doe.gov/pub/oil_gas/natural_gas/analysis_publications/maps/maps.htm

A. What is hydraulic fracturing?

Hydraulic fracturing typically involves millions of gallons of fluid that are pumped into an oil or gas well at high pressure to create fractures in the rock formation that allow oil or gas to flow from the fractures to the wellbore.[6] Fracturing fluid is roughly 99% water but also

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[1] Ground Water Protection Council and ALL Consulting. *Modern Shale Gas Development in the United States: A Primer*. Prepared for U.S. Department of Energy, Office of Fossil Energy and National Energy Technology Laboratory. April 2009. Print.

[2] U.S. Energy Information Administration. *Natural Gas Year-In-Review 2009*. July 2010. Web. May 3, 2011, http://www.eia.gov/pub/oil_gas/natural_gas/feature_articles/2010/ngyir2009/ngyir2009.html

[3] Modern Shale Gas Development*, supra* at note 1, p.7.

[4] Kargbo, D.M., Wilhelm, R.G., Campbell, D.J. 2010. Natural Gas Plays in the Marcellus Shale: challenges and potential opportunities. *Environmental Science & Technol*ogy *44:*5679–5684.

[5] U.S. Energy Information Administration. *Annual Energy Outlook 2011 with Projections to 2035*. December 2010. Web. Accessed April 19, 2011, http://www.eia.doe.gov/oiaf/aeo/electricity.html.

[6] U.S. Department of Energy, Office of Fossil Energy, and National Energy Technology Laboratory. *State Oil and Natural Gas Regulations Designed to Protect Water Resources*. May 2009. Print, p.21.

contains numerous chemical additives as well as propping agents, such as sands, that are used to keep fractures open once they are produced under pressure.[7,8] The chemicals added to fracturing fluid include friction reducers, surfactants, gelling agents, scale inhibitors, acids, corrosion inhibitors, antibacterial agents, and clay stabilizers.[9,10] Depending on the site, 15-80% of the fracturing fluid injected is recovered as flowback water at the well head.[11] In addition, a considerable amount of water that comes to the surface, often called "produced water," over the lifetime of the well is highly saline water that originates deep underground in the shale formation.

Hydraulic fracturing substantially increases the extraction of natural gas from unconventional sources. The Interstate Oil and Gas Compact Commission (IOGCC) estimates that hydraulic fracturing is used to stimulate production in 90% of domestic oil and gas wells, though shale and other unconventional gas recovery utilizes high-volume hydraulic fracturing to a much greater extent than conventional gas development does.[12] Horizontal wells, which may extend two miles from the well pad, are estimated to be 2-3 times more productive than conventional vertical wells, and see an even greater increase in production from hydraulic fracturing.[13] The alternative to hydraulic fracturing is to drill more wells in an area, a solution that is often economically or geographically prohibitive.[14]

B. Hydraulic fracturing and drinking water

Approximately 44 million Americans rely on a private water supply for household and agricultural use, typically sourced from shallow aquifers.[15] In areas of extensive shale gas drilling, some homeowners have claimed that hydraulic fracturing has contaminated their drinking-water wells with methane and waste waters.[16]

Shale gas is typically comprised of over 90% methane.[17] The migration of methane gas to nearby private drinking water wells is a concern with hydraulic fracturing and natural-gas extraction in general. Methane is not regulated in drinking water because it does not alter

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[7] U.S. Environmental Protection Agency. Office of Research and Development. *Hydraulic Fracturing Research Study.* 29 June 2010. Web. March 29, 2011, http://www.epa.gov/safewater/uic/pdfs/hfresearchstudyfs.pdf.
[8] Zeik, Travis. "Student Work: Hydraulic Fracturing Goes to Court: How Texas Jurisprudence on Subsurface Trespass Will Influence West Virginia Oil and Gas Law." *West Virginia Law Review* 12.2 (Winter 2010): 599. Print.
[9] Kaufman, P., G.S. Penny, J. Paktinat. "Critical Evaluation of Additives Used in Shale Slickwater Fractures." *Society of Petroleum Engineers.* Paper SPE 119900. Nov. 2008. Print.
[10] Hydraulic Fracturing Goes to Court, *supra* at note 8.
[11] Hydraulic Fracturing Research Study, *supra* at note 7, p.2..
[12] Railroad Commission of Texas. *Testimony Submitted To The House Committee On Energy And Commerce By Victor Carrillo, Chairman, Texas Railroad Commission, Representing The Interstate Oil And Gas Compact Commission*. 10 Feb. 2005. Print.
[13] *Id.*
[14] State Oil and Natural Gas Regulations, *supra* at note 6, p.22.
[15] Hutson, Susan, *et al*. *Estimated Use of Water in the United States in 2000*. U.S. Geological Survey Circular 1268. May 2004:16. Print.
[16] *See, e.g.,* Pennsylvania State College of Agricultural Sciences Cooperative Extension. *Water Facts 28: Gas Well Drilling and Your Private Water Supply*. Mar. 2010. Print.
[17] Jenkins, Creties D. and Charles M. Boyer II. "Coalbed- and Shale-Gas Reservoirs." *Society of Petroleum Engineers.* Distinguished Author Series. Feb. 2008. Print.

the color, taste, or odor of water and is not known to affect water's potability.[18] Methane can, however, pose an asphyxiation and explosion hazard in confined spaces when it moves from the water into the air.[19] The U.S. Department of the Interior recommends immediate action be taken to ventilate the well head when dissolved methane is present in water in concentrations greater than 28 milligrams per liter (mg/L).[20] At a concentration of more than 10 mg/L, occupants in the surrounding area should be warned, ignition sources should be removed from the area, and remediation should be performed to reduce the methane concentration to less than 10 mg/L.[21]

The potential for contamination from wastewaters associated with hydraulic fracturing depends on many factors, including the toxicity of the fracturing fluid and the produced waters, how close the gas well and fractured zone are to shallow ground water, and the transport and disposal of wastewaters.[22] Despite precautions by industry, contamination may sometimes occur through corroded well casings, spilled fracturing fluid at a drilling site, leaked wastewater, or, more controversially, the direct movement of methane or water upwards from deep underground.[23] To address these and other concerns, states such as Ohio and Arkansas have recently amended their standards for well construction and casing to help prevent leaks and accidents.[24]

During the first month of drilling and production alone, a single well can produce a million or more gallons of waste water that can contain pollutants in concentrations far exceeding those considered safe for drinking water and for release into the environment.[25] These pollutants sometimes include formaldehyde, boric acid, methanol, hydrochloric acid, and isopropanol, which can damage the brain, eyes, skin, and nervous system on direct contact.[26] Another potential type of contamination comes from naturally occurring salts, metals, and radioactive chemicals found deep underground. After hydraulic fracturing, fracking fluids and deep waters flow through the well to the surface along with the shale gas.[27]

A recent study by Osborn and colleagues in the Proceedings of the National Academy of

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[18] U.S. Department of the Interior, Office of Surface Mining. *Technical Measures for the Investigation and Mitigation of Fugitive Methane Hazards in Areas of Coal Mining*. Sept. 2001. Print.
[19] *Id.*
[20] *Id.*
[21] *Id.*
[22] Wiseman, Hannah. "Untested Waters: The Rise of Hydraulic Fracturing in Oil and Gas Production and the Need to Revisit Regulation." *Fordham Environmental Law Review* 20 (2009):115, 127-42. Print.
[23] Water Facts 28, *supra* at note 16, p. 2.
[24] Ohio Legislative Service Commission (2010). Sub. S.B. 165. Web. May 3, 2011: http://www.lsc.state.oh.us/analyses128/10-sb165-128.pdf; Arkansas Oil and Gas Commission (2011); Rule B-19 Requirements for Well Completion Utilizing Fracture Stimulation Online. Web. May 3, 2011, http://www.aogc.state.ar.us/PDF/B-19 Final 1-15-11.pdf.
[25] Water Facts 28, *supra* at note 16, p. 2.
[26] Coffman, Steve. *The Safety of Fracturing Fluids – A Quantitative Assessment*. Committee to Preserve the Finger Lakes. 4 August 2009. Print.
[27] Hydraulic Fracturing Research Study, *supra* at note 7, p.2.

Sciences, USA[28] provides to our knowledge the first systematic evidence of methane contamination of private drinking-water in areas where shale gas extraction is occurring. The research was performed at sites above the Marcellus and Utica formations in Pennsylvania and New York. Based on groundwater analyses of 60 private water wells in the region, methane concentrations were found to be 17-times higher on average in areas with active drilling and extraction than in non-active areas, with some drinking-water wells having concentrations of methane well above the "immediate action" hazard level.[29] Average and maximum methane concentrations were higher in shallow water wells within approximately 3,000 feet (1000 meters) of active shale-gas wells. Isotopic data and other measurements for methane in the drinking water were consistent with gas found in deep reservoirs such as the Marcellus and Utica shales at the active sites and matched gas geochemistry from shale-gas wells sampled nearby. The study found no evidence of contamination from hydraulic fracturing fluids or saline produced waters.[30]

Given the results described in the study of Osborn and colleagues,[31] and the controversy and public concerns surrounding shale gas extraction, in this paper we offer some research and policy recommendations for consideration.

I. Research Recommendations

Based on the results of Osborn and colleagues[32] and the need for greater knowledge of the environmental effects of shale-gas drilling and hydraulic fracturing, we offer six research recommendations to improve public confidence in shale-gas extraction. The first four research recommendations address the presence of methane and other gases in drinking water and follow directly from the results of Osborn and colleagues. The fifth and sixth recommendations focus on issues of water quality and disposal associated with hydraulic fracturing. The final two policy recommendations address horizontal drilling and hydraulic fracturing more generally (see Section III). Interested readers should also examine the U.S. Environmental Protection Agency's draft research plan examining the potential consequences of hydraulic fracturing on drinking water resources.[33]

A. Initiate Medical Review of the Health Effects of Methane

Methane is not regulated as a contaminant in public water systems through the EPA's National Primary Drinking Water Regulations (NPDWR). Methane in drinking water is also, to our knowledge, unregulated by any state in the United States. Public health concerns for methane have traditionally emphasized cases of explosions and flammability and, in very high concentrations, asphyxiation. For instance, after a house exploded in Bainbridge

[28] Osborn, SG, A Vengosh, NR Warner, RB Jackson 2011 Methane contamination of drinking water accompanying gas-well drilling and hydraulic fracturing. Proceedings of the National Academy of Sciences, U.S.A. ; DOI: 10.1073/pnas.1100682108.
[29] *Id.*
[30] *Id.*
[31] *Id.*
[32] *Id.*
[33] U.S. Environmental Protection Agency 2011 Draft Plan to Study the Potential Impacts of Hydraulic Fracturing on Drinking Water Resources. Office of Research and Development, U.S. EPA, Washington, D.C.

Township, Ohio, the state's Department of Natural Resources issued a 150-page report on the source of the methane contamination.[34] The Department's Division of Mineral Resources Management concluded that a faulty gas-well casing was the likely source of the gas in this home and in other homes in the area.

Outside of the extreme cases of explosion, flammability, and asphyxiation, methane is not typically viewed as a health hazard. Compared to longer-chain and especially unsaturated hydrocarbons (molecules with double and triple carbon bonds), methane is relatively unreactive. Nonetheless, we found essentially no peer-reviewed research on its health effects at lower concentrations in water or air. One study of relatively high concentrations in air recommended that exposure be limited to 10% of the lower explosive limit (LEL) to avoid narcosis and to reduce the explosive hazards of the gases.[35]

Based on public concerns about the consequences of methane in drinking water, and the lack of peer-reviewed research on its health effects, we recommend that an independent medical review be initiated to evaluate the health effects of methane in drinking water and households. If a panel of health-care professionals concludes that systematic research is needed, then toxicity tests and epidemiological observations should begin quickly to examine the consequences of ingesting and breathing methane. Depending on their recommendation, it is even possible that the EPA might consider defining a maximum contaminant level for methane as a new drinking-water standard. If the panel instead concludes that systematic research is unnecessary, then their medical summary, and the rationale for their conclusion, would help to assuage concerns about the gas and its associated liabilities. Similar consideration could also be given to ethane and propane, additional constituents often found in shale gas.

B. Construct a National Database of Methane, Ethane, and Propane Concentrations and Other Chemical Attributes in Drinking Water

Comprehensive data on methane and other hydrocarbons in water would be useful for determining whether relatively high concentrations of methane at a location occur naturally or are instead associated directly with drilling and natural-gas extraction. A comprehensive database should include information for gas concentrations and stable isotopes of the gases (^{13}C and ^{2}H), water (^{2}H), and dissolved inorganic carbon in the water (^{13}C) along with other chemical and physical variables. It will be useful for differentiating methane generated by microbes in shallower layers and methane generated deep underground by heat that characterizes shale gas. Researchers will also be able to use the data to build predictive frameworks for identifying potential sites where methane could occur in elevated concentrations in the United States. The U.S. Environmental Protection Agency and U.S. Geological Survey are two agencies that might lead such an effort. For

[34] Report on the Investigation of the Natural Gas Invasion of Aquifers in Bainbridge Township of Geauga County, Ohio. Ohio Department of Natural Resources, Division of Mineral Resources Management. September, 2008.

[35] Drummond, I. 1993. Light Hydrocarbon Gases: A Narcotic, Asphyxiant, or Flammable Hazard? Applied Occupational and Environmental Hygiene 8:120 – 125.

instance, the USGS national groundwater database[36] could be expanded to include a broader representation of methane and other hydrocarbons.

C. Evaluate the Mechanisms of Methane Contamination in Drinking Water

Where methane contamination of water occurs, the effects of horizontal drilling and hydraulic fracturing deep underground need to be separated from the possible effects of methane leakage from a poorly constructed gas-well casing nearer the surface. The key issue is whether hydraulic fracturing itself can increase leaks of methane or other contaminants all the way to the surface. When gas wells are thousands of feet deep – and far below the shallow aquifers that typically provide drinking water – contamination is often stated to be impossible due to the distance between the well and the drinking water. Although this seems reasonable in most (and possibly all) cases, field and modeling studies should be undertaken to confirm this assumption. We recommend a federal research program, coordinated in part through the U.S. Geological Survey or the U.S. Department of Energy, to evaluate this possibility through field work and modeling. Understanding any cases where this assumption is incorrect will be important – when, where, and why they occur – to limit problems with hydraulic fracturing operations.

D. Refine Estimates for Greenhouse-Gas Emissions of Methane Associated with Shale-Gas Extraction

Studies have estimated methane losses to the atmosphere from natural-gas production to be between 1 and 3% of total gas production per well.[37] The majority of these losses are "fugitive emissions" from the movement and transport of methane, particularly leaks at compressor stations and in underground pipes. In a summary for the U.S. Environmental Protection Agency, Kirchgessner and colleagues estimated methane emissions associated with the U.S. gas industry to be $6.04 \pm 2.01 \times 10^{12}$ g CH_4 in 1991, an amount that accounted for 19-21% of all U.S. methane emissions attributable to human activities.[38] A new analysis from Cornell University suggests that methane emissions associated with shale-gas extraction may be substantially higher.[39] That study estimated that 3.6 to 7.9% of the methane from shale-gas production escapes to the atmosphere over the lifetime of a well through leaks and venting. Regardless of the accuracy of the new estimate, the controversy it generated highlights weaknesses in the data used for such calculations and demonstrates that no consensus exists as to the extent of methane losses to the atmosphere from shale-gas extraction.

We propose that a joint industry-government-academia panel be convened to estimate total methane emissions from shale-gas extraction and natural-gas extraction more generally. The panel should determine the most important sources of methane losses over the lifetime of a well and identify key uncertainties in those sources. The combination of better constraints on the quantities involved, and the accompanying uncertainties, can then

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[36] http://waterdata.usgs.gov/usa/nwis/gw

[37] Kirchgessner DA, Lott RA, Cowgill RM, Harrison MR, Shires TM 1997 Estimate of methane emissions from the U.S. natural gas industry. Chemosphere 35: 1365-1390.

[38] *Id*.

[39] Howarth RW, R Santoro, A Ingraffea 2011 Methane and the greenhouse-gas footprint of natural gas from shale formations. Climatic Change doi:10.1007/s10584-011-0061-5.

be used to prioritize future research.

E. Systematically Sample Drinking Water Wells and Deep Formation Waters

To plan for and mitigate any health and safety issues that arise from hydraulic fracturing and shale-gas drilling, states should ensure that scientists collect extensive baseline data on water quality in drinking water prior to exploration and drilling. This baseline sampling would provide the basis for chemical characterization of the shallow ground water and should then be followed with monitoring to evaluate the long-term impact of hydraulic fracturing and gas drilling. The monitoring programs should include diverse chemical and isotopic variables useful for identifying possible contamination.

There are several existing water-quality testing programs that could be evaluated in whole or in part to create comprehensive water testing requirements at the state level. The National Park Service (NPS) and U.S. Geological Survey (USGS) Water Quality Partnership Program already has a baseline water-quality testing program for private wells. The program, with support from the Clean Water Action Plan, monitors water quality in national parks and provides information to park resource managers to help them make scientifically sound policy decisions.[40] One of the partnership's 2011 projects will establish a record of baseline water-quality in national park units in the Marcellus Shale.[41]

At the level of individual states, some aspects of Pennsylvania's requirements could also be considered elsewhere. In Pennsylvania, drilling companies are presumed to be responsible for water contamination that occurs within a 1,000-foot radius of a drilling site if it occurs within six months of the completion of the well.[42] Because of this, gas well operators in Pennsylvania typically test all drinking water supplies within 1,000 feet of their operation before drilling. In fact the results of Osborn and colleagues[43] suggest that 3,000 feet (1,000 meters) is a more appropriate distance over which to sample ground water before drilling and hydraulic fracturing begin. We recommend that this distance be considered for testing. Testing in the Pennsylvania program must be conducted by an independent state-certified laboratory to be admissible in court, and the property owner has a right to receive a copy of the results.

Policies emulating the Pennsylvania requirements should consider expanding the geographic reach of the program. Further discussions are also needed on the frequency of follow-up testing once drilling occurs and the chemicals for which the water is tested. In the interest of transparency, results for water-quality testing should be made publicly

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[42] State Review of Oil and Natural Gas Environmental Regulations (STRONGER). "Pennsylvania Hydraulic Fracturing State Review" September 2010.
(http://www.strongerinc.org/documents/PA%20HF%20Review%20Print%20Version.pdf)
[43] *Id*. at 28

available without providing information that would violate the privacy rights of the property owner.

In New Jersey, where the Private Well Testing Act requires testing of private wells upon the sale of property, test results are reported to the person who requested the testing, the Department of Environmental Protection, and the local health authority.[44] Both the Department of Environmental Protection and the local health authority are required to keep the address of tested wells confidential to protect the rights of the property owner. New Mexico takes a similar approach to privacy, providing summaries of well-water quality data by general area when requested, but keeping names, addresses, phone numbers, and GPS coordinates of homeowners and wells confidential.[45] A range of options can be evaluated based on what different states are already doing.

F. Study Disposal of Waste Waters from Hydraulic Fracturing and Shale-Gas Extraction

Hydraulic fracturing produces saline and toxic waste waters (including some with potentially high naturally occurring radioactivity) that flow out of the gas wells. Currently, wastewaters originating from hydraulic fracturing and gas production are disposed of by (1) transport to wastewater and/or brine treatment centers, where they are treated and released to local surface water; (2) injection into deep geological formations that are presumably disconnected from the overlying shallow drinking water aquifers; (3) recycled using a variety of treatment technologies and re-injected as fracturing fluid; and (4) spread on local roads for dust suppression. Individual states have different regulations for disposing of such water, but there is to our knowledge no comprehensive evaluation of the long-term impacts of wastewater disposal of these methods. We recommend that a detailed evaluation of the safety of the disposal methods be conducted, particularly for wastewater disposal to streams and rivers. The study should evaluate what amounts of different contaminants, including naturally occurring radioactive chemicals, are removed in the wastewater treatment plants and the brine treatment centers and what are the long-term ecological effects of the chemicals not removed downstream from the treatment facilities.

II. Policy Recommendations

In addition to the six research recommendations described above, we offer two policy recommendations for discussion. One concerns the possible regulation of hydraulic fracturing under the U.S. Safe Drinking Water Act and the other recommends disclosure of the chemicals in hydraulic fracturing fluids, so that potential contamination could be traced more accurately.

A. Consider Regulating Hydraulic Fracturing Under the Safe Drinking Water Act

The Safe Drinking Water Act (SDWA) Underground Injection Control Program is designed to protect drinking water from contamination by requiring the EPA or EPA-authorized

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[44] New Jersey Private Well Testing Act. N.J.S.A. 58:12A-26, et. seq. 23 Mar. 2001. Print.

[45] New Mexico Environment Department. *Free Well Testing*. 16 Mar. 2009. Web. May 3, 2011, http://www.nmenv.state.nm.us/fod/LiquidWaste/well.testing.html.

states to implement programs that prevent the underground injection of fluids from endangering drinking water.[46] Despite the fact that hydraulic fracturing involves the underground disposal of fluids in some states and surface disposal of wastewater in other states, such as Pennsylvania, the EPA has never regulated hydraulic fracturing under the SDWA. The 2005 Energy Policy Act codified this by specifically excluding "the underground injection of fluids or propping agents (other than diesel fuels) pursuant to hydraulic fracturing operations related to oil, gas, or geothermal production activities" from the definition of "underground injection."[47]

In 2009, companion bills granting the EPA authority over hydraulic fracturing under the SDWA were introduced in both houses of Congress.[48] Together they constituted the "Fracturing Responsibility and Awareness of Chemicals Act," also known as the "FRAC Act." Although both bills were referred to committee in their respective houses, neither was reported out of committee and both bills expired at the close of the 111th session of Congress. That the FRAC Act did not come to a vote is widely attributed to the EPA's ongoing study of detrimental impacts on drinking water from hydraulic fracturing, which is expected to be released in interim form in 2012 and to be completed in 2014.[49] Congress requested the study, relying on the best available science as well as independent sources of information, in response to concerns from citizens about drinking water problems attributed to hydraulic fracturing. The FRAC Act was reintroduced in both houses of Congress on March 15, 2011. In our view, the inclusion of hydraulic fracturing in the SDWA, whether this is accomplished through the passage of the FRAC Act or through some other means, would strengthen public confidence in hydraulic fracturing and natural-gas extraction.

B. Fully Disclose Chemicals Used In Hydraulic Fracturing

Natural gas companies are not required to disclose the identity of the chemical constituents in hydraulic fracturing fluid under federal law or most state law and guard the makeup of hydraulic fracturing fluids as a trade secret.[50] The EPA issued a voluntary request to nine hydraulic service providers in September, 2010, requesting information on the chemical composition of hydraulic fracturing fluids as part of their ongoing study of hydraulic fracturing, indicating that they had the legal authority to compel disclosure if necessary.[51] Other federal legislation has also attempted, thus far unsuccessfully, to compel disclosure

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[46] Safe Drinking Water Act (SWDA), § 42 USC 300h. 2008. Print.

[47] Safe Drinking Water Act (SWDA). 2005. Pub. L. No. 109-58 (codified at 42 USC 300h (d)(1)(B)(ii)). 2008. Print.

[48] Fracturing Responsibility and Awareness of Chemicals Act. S. 1215 and H.R. 2766. 9 June 2009. Print.

[49] Spence, David. *Fracking Regulations: Is Federal Hydraulic Fracturing Regulation Around the Corner?* Energy Management and Innovation Center. Web. May 3, 2011, http://blogs.mccombs.utexas.edu/energy/energy-management-briefs/fracking-regulations-is-federal-hydraulic-facturing-regulation-around-the-corner/.

[50] Horowitt, Dusty. *Free Pass for Oil and Gas: Environmental Protections Rolled Back as Western Drilling Surges*. Environmental Working Group. Mar. 2009. Web. March 29, 2011, http://www.ewg.org/reports/Free-Pass-for-Oil-and-Gas.

[51] U.S. Environmental Protection Agency. "Letter Sent by EPA to Nine Hydraulic Service Providers." 9 Sept. 2010. Web. May 3, 2011, http://water.epa.gov/type/groundwater/uic/class2/hydraulicfracturing/upload/HFvoluntaryinformationrequest.pdf.

of chemicals used in hydraulic fracturing. For example, the recently reintroduced FRAC Act would require a full disclosure of chemicals used in hydraulic fracturing, though it would not require disclosure of the proprietary chemical formulas.[52] Any regulation should strike a balance between respecting the intellectual property rights of the industry and protecting people and the environment from potential contamination, including homeowners and the workers at drilling sites.

At the state level, Colorado requires limited disclosure of toxic chemicals in hydraulic fracturing fluids,[53] and Pennsylvania began requiring disclosure of the chemicals in such fluids in February of 2011. Wyoming recently adopted regulation that not only requires disclosure, but makes the information publicly available, although they can provide exemptions for trade secret protection.[54] Department of the Interior Secretary Ken Salazar recently announced his department's plans to require disclosure of fracturing chemicals used on public lands, and interior officials have confirmed that Wyoming's disclosure rules will serve as a model for regulation.[55] States should consider adopting disclosure requirements similar to the Wyoming rules.

IV. Conclusions

Natural gas has been used as a domestic and industrial fuel source for over a century. It contains more energy per pound than coal. When burned, it produces almost none of the mercury, sulfur dioxide, and particulates that burning coal produces, nor does it require destructive mountain-top mining and other approaches inherent in coal production. As a cleaner source of energy, and as a bridge to a carbon constrained future, natural gas has many desirable qualities. Despite these benefits, more research is needed to assess the mechanisms of water contamination and possible methane losses to the atmosphere. Moreover, some additional oversight may be needed to protect communities and the environment from water contamination near extraction and disposal sites.

The research and policy recommendations presented here are provided in the spirit of making natural-gas extraction safer and more consistent across companies, locations, and time. Decisions regarding the extent to which natural gas extraction should be regulated must balance public health and safety, energy needs, and the inevitable bureaucracy that regulation brings. Based on the results of Osborn and colleagues and the additional background provided here, we believe that horizontal drilling, hydraulic fracturing, and shale-gas extraction in general would benefit from 1) better-coordinated, and sustained scientific study; 2) a review of the potential health consequences of methane and other hydrocarbons in drinking water; 3) industry-driven approaches to develop safer and more

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[52] Fracturing Responsibility and Awareness of Chemicals Act. S. 1215 and H.R. 2766. 9 June 2009. Print.

[53] Oil and Gas Conservation Act of the State of Colorado. Colo. Rev. Stat. Sec. 34-60-100, et. seq.

[54] Soraghan, Mike. "Wyo. Natural Gas Fracking Rules for Point the Way for Public Disclosure of Chemicals Used." *New York Times.* 20 Dec. 2010. Web. May 3, 2011, http://www.nytimes.com/gwire/2010/12/20/20greenwire-wyo-natural-gas-fracking-rules-for-point-the-w-18753.html.

[55] Taylor, Phil. *Interior to consider disclosure rules for fracking fluids.* E&E Publishing, LLC. 30 Nov. 2010. Web. May 3, 2011, http://www.eenews.net/public/eenewspm/2010/11/30/3.

consistent extraction technologies, and 4) consideration of stronger state or federal regulation. Other topics not discussed here but that would benefit from increased study include the treatment and disposal of waste waters; current practices include wastewater treatment with subsequent release into surface streams and rivers, or disposal through injection into deep geological formations.

As the United States and other countries continue to develop new methods for accessing unconventional sources of energy, and as hydraulic fracturing becomes increasingly common for extracting conventional oil and gas reserves, the questions that we have raised are likely to become more common. Developing a comprehensive approach to industry oversight and regulation, based on scientific data and on appropriate state and federal oversight, will provide a positive path forward for future energy extraction technologies.