ADDENDUM INDEX

APPENDIX #	DOCUMENT DESCRIPTION	PAGE #
1	Affidavit of Carol Kwiatkowski (with references and Curriculum Vitae)	1-9
2	Hazard Assessment Articles: Natural Gas Operations from a Public Health Perspective, By T. Colborn, C. Kwiatkowske, K. Schultz, and M. Bachran	10-27
3	Human and Ecological Risk Assessment: An International Journal, October 11, 2013: An Exploratory Study of Air Quality Near Natural Gas Operations, By T. Colborn, K. Schultz, L. Herrick, C. Kwiatkowski	28-54
4	Affidavit of Ron Throupe (with Curriculum Vitae)	55-69
5	Journal of Real Estate Literature, Volume 21, Number 2, 2013: A Review of Hydro "Fracking" and Its Potential Effects on Real Estate, By Ron Throupe, Robert A. Simons, Xue Mao	70-97
6	Resource and Energy Economics 27, 2005: The impact of oil and natural gas facilities on rural residential property values: a spatial hedonic analysis, By P.C. Boxall, W.H. Chan, M.L. McMillan	98-119
7	American Journal of Agriculture and Economics, Volume 96, Number 1, September 2013: Is the Shale Energy Boom a Bust for Nearby Residents? Evidence from Housing Values in Pennsylvania, By Sathya Gopalakrishnan, H.A. Klaiber	120-143
8	The Review of Regional Studies, Volume 42, Number 2, 2013: Unconventional Shale Gas Development and Real Estate Valuation Issues, By C.A. Lipscomb, Yongsheng Wang, and S.J. Kilpatrick	144-158
9	Affidavit of Jim Hughes (with Resume and Presentation Slides explaining Underbalanced Drilling)	159-178
10	New York State Department of Health Completes Review of High-volume Hydraulic Fracturing, http://www.dec.ny.gov/press/100055.html, For Release: Wednesday, December 17, 2014.	179-180
11	A Public Health Review of High Volume Hydraulic Fracturing for Shale Gas Development, December 2014	181-364
12	A Dictionary for the Oil and Gas Industry, 1st Ed., The University of Texas Continuing Education- Petroleum Extension Service (Austin, TX 2005)	365-388

DISTRICT COURT, BOULDER COUNTY, COLORADO Address: 1777 Sixth Street Boulder, Colorado 80302 Phone: (303) 441-3771	
PLAINTIFFS: COLORADO OIL & GAS ASSOCIATION; and COLORADO OIL & GAS CONSERVATION COMMISSION; **PLAINTIFF-INTERVENOR:** TOP OPERATING, CO. v. **DEFENDANT:** CITY OF LONGMONT, COLORADO **DEFENDANT-INTERVENORS:** OUR HEALTH, OUR FUTURE, OUR LONGMONT; SIERRA CLUB; FOOD & WATER WATCH; and EARTHWORKS.	**COURT USE ONLY** Case Number: 2013CV63 Div.: 3 Courtroom: K
Attorneys for Our Health, Our Future, Our Longmont, Sierra Club, Food and Water Watch, and Earthworks Name: Kevin Lynch (Atty. Reg. #39873) Address: 2255 E. Evans Avenue, Suite 335 Denver, CO 80208 Phone Number: 303.871.6140 FAX Number: 303.871.6847 E-mail: klynch@law.du.edu *Attorney for Sierra Club and Earthworks* Name: Eric Huber (Colo. Bar No. 40664) Address: 1650 38th St. Ste. 102W Boulder, CO 80301 Phone Number: 303.449.4494, ext. 101 E-mail: eric.huber@sierraclub.org	

AFFIDAVIT OF CAROL KWIATKOWSKI

1. My name is Carol Kwiatkowski. I am of legal age and competent to give this declaration. This Affidavit is based on my personal knowledge and experience.

2. I am the Executive Director of TEDX, The Endocrine Disruption Exchange. I am also an adjunct faculty member at the University of Colorado Boulder, in the Department of Integrative Physiology. Prior to working for TEDX, I was an Assistant Professor at the University of Colorado, Denver.

1

3. I have a PhD and a Masters degree in Cognitive Science from the University of Denver. I have published a total of 25 peer-reviewed articles. My CV, which includes a full list of my positions, degrees, and publications, is attached as Exhibit 1.

4. I am an author of two scientific articles on natural gas operations, specifically related to the impacts of natural gas operations on human health. These articles are attached as Exhibit 2 and 3.

5. The Endocrine Disruption Exchange, known as TEDX, is a U.S.-based non-profit organization founded in 2003 and located in Paonia, Colorado. At TEDX, my fellow researchers and I compile and disseminate scientific evidence on the health and environmental damage caused by low-level exposure to chemicals, primarily those that interfere with hormone, or endocrine, action, otherwise known as endocrine disruptors.

6. A major concern with endocrine-disrupting chemicals is that they are associated with adverse health effects at very low concentrations: parts per billion and parts per trillion. These are the concentrations at which hormones function in our bodies. Exposures at these levels are most devastating when exposure occurs prenatally or in early childhood, when the body's systems are developing and damage can be irreversible.

7. As part of my work, I track studies that relate to natural gas operations, with a specific emphasis on health impacts. I have read a number of papers publishing the results of these studies, which are identified in the list attached as Exhibit 4. All of these studies are peer-reviewed and are the type of data and other information that I and others in my field rely upon. I consider them authoritative and reliable on the matters addressed in the papers.

8. TEDX was one of the first organizations to begin identifying and sharing health information on chemicals used in unconventional natural gas development, commonly known as fracking. My research shows that there are chemicals in the air associated with natural gas operations, and numerous health effects have been associated with those chemicals in the scientific literature.

9. TEDX has developed a variety of resources for the public about the health impacts of chemicals used in fracking operations. This includes two peer-reviewed publications (Colborn, *et al.*, 2011, 2014) and a video tutorial for the public about natural gas operations. It also includes a spreadsheet on the internet showing chemicals used in natural gas development, with a list of 980 products containing 649 chemicals, with their associated health effects as identified in the scientific literature.

10. In addition to our information on gas operations in Colorado and other states, TEDX's website also provides analyses of chemicals from a drilling operation in Wyoming (prior to fracking) and in drilling reserve pits in New Mexico.

11. In the course of this research, my fellow researchers at TEDX and I began to realize that air pollution from natural gas operations was perhaps a more serious threat than water contamination, and yet air pollution was not being addressed by the regulatory community.

12. We prepared a table based on our 2011 paper in which we reviewed the health effects of 353 chemicals used during natural gas operations by searching government and scientific literature for published studies. The Table is attached as Exhibit 5.

13. This table shows the percent of chemicals that have health effects in each of 12 different categories. Nearly all of the chemicals are reported to have skin, eye and sensory organ effects, followed by respiratory effects, effects on the gastrointestinal system, on the brain and nervous system, and more, with a substantial number of carcinogens.

14. Thirty-seven percent (37%) of the chemicals we reviewed are volatile, meaning that the chemicals take on a gaseous form and are dispersed through the air. In every category but one, the volatile chemicals are more likely to have health effects than the soluble ones.

15. These 353 chemicals are just those that are used during drilling and hydraulic fracturing. There are several other sources of air pollution, including volatile chemicals that are released from underground during the exploration and production process, chemicals used during development and maintenance of the well pad and equipment, and numerous chemicals from mobile and stationary combustion sources.

16. Based on this research, we determined we needed to gather more information about what chemicals were in the air. In 2010, we conducted an air sampling study in Garfield County, on the western slope of Colorado, which is heavily impacted by natural gas operations.

17. For this study, air samples were collected at a neighborhood location 0.7 miles from where a well pad with 16 wells was being built. There were also 130 producing wells within a mile radius of the sampling site. The purpose of this exploratory study was to see what the average citizen living in a heavily developed gas patch might be exposed to.

18. During the course of a year, weekly air samples were collected by a trained technician following standard operating procedures for collecting and shipping the samples. We used independent accredited laboratories to analyze the samples and they conducted EPA standard analytical protocols. Given what we knew about the chemicals being used, the samples were analyzed for a wide variety of chemicals – 153 in total.

19. A total of 61 chemicals were identified through our sampling, many of them associated with natural gas operations. Shown on Exhibit 6 are the chemicals identified in at least half of the samples. Methane, ethane, propane, toluene, formaldehyde, acetaldehyde, and naphthalene are all associated with oil and gas operations and were detected in every sample.

20. Certain chemicals identified are referred to as the natural gas fingerprint. They are not the most dangerous chemicals health-wise, but they can be used to identify the 'source' of air pollution as being associated with natural gas development. Those signature chemicals were found in a very high percentage of our samples. In contrast, we rarely found any chemicals like ethene and other alkenes, which have been sourced to road-based air pollution.

21. I have reviewed the professional and scientific literature on health effects of the 61 chemicals, and it shows that more than half have been shown to affect the brain and central nervous system, causing headache, dizziness, confusion, memory loss, tingling in the extremities, peripheral neuropathy, all similar to complaints from residents and workers in the gas fields. They can also damage the liver and the metabolic system, and the endocrine system, affecting reproductive health, development in the womb, and other endocrine related endpoints. Nearly half of the chemicals affect the immune system, respiratory system, and the heart. They also irritate the skin, eyes, and other sensory organs, and have other effects. Many of these are health problems that are not expressed until much later in life, long after exposure took place.

22. The chemical methylene chloride was found in 73% of the air samples, and at times it was found in extremely high concentrations—up to 1730 parts per billion (ppb). At one point the lab called us to request another sample because they suspected contamination and they were concerned about exposure to such high levels. Methylene chloride is a powerful solvent that we later learned is stored on well pads for cleaning purposes and can be poured down the bore hole when the drill bit gets stuck. However, it may not appear on lists of known chemicals used during natural gas operations because typically only chemicals injected during hydraulic fracturing are disclosed, not those used above ground on the well pad or during drilling.

23. Polycyclic aromatic hydrocarbons (PAHs) were found in very low concentrations—in parts per trillion. However other research I have reviewed and deemed reliable shows that these low levels can have significant effects (see for example Perera *et al.*, 2004, 2006, 2009, 2012; Rundle *et al.*, 2012). In one study, done in New York City, pregnant women wore backpack monitors to measure the PAHs in the air they were breathing. Eight PAHs were identified.

24. Our study showed that levels of the same eight PAHs were three times higher in Garfield County than in New York City. This shocked us because PAHs are typically associated with combustion sources, and we were sampling in a very rural area, with little evidence of combustion related chemicals in the air.

25. In the New York research, the children of the pregnant women were evaluated and at birth they found increases in preterm births, low birth weight babies, and babies with smaller skull circumferences among those exposed to higher levels of PAHs. As the children's development was tracked over time, the researchers have published studies documenting associations between PAHs and lower scores of mental development at 3 years of age; lower IQ scores at age 5; and attention and behavioral problems at 7 years of age—and most recently, childhood obesity.

26. Based on my expertise, I can identify these symptoms as the kind of effects associated with prenatal exposure to endocrine disrupting chemicals.

27. Other recent studies are relevant to endocrine disruption, including a study by Kassotis, *et al.*, published in December 2013, which I have read and deemed reliable on the subject matter it addresses. The researchers in that study measured estrogenic and androgenic properties of samples they collected from surface and ground water in Garfield County – near wells with spills, in river water near gas activity, and also in control sites in Colorado and Missouri. They also measured hormone properties of 12 chemicals used in natural gas operations. Also, they reported results from a separate group at the University of Colorado who sampled some of the same sites and identified chemicals that were present. They found that water samples from test sites in Garfield County had more hormone activity than the control sites (the Colorado River was at moderate levels). They also found that specific chemicals known to be used in natural gas operations, some of which were detected at the sampling sites by the Colorado group, displayed hormone properties similar to those found in the water samples. This is further evidence of endocrine disrupting chemicals potentially associated with natural gas operations.

28. Another peer-reviewed study (McKenzie, *et al.*, 2014) which I find to be of reliable authority was a retrospective cohort of 125,000 birth records in 57 rural Colorado counties. The researchers assigned each mother/infant pair a score based on how many wells were within 10 miles of where the mother lived at the time of the baby's birth (the density) and how far away the wells actually were from the residence (the proximity). The results showed a linear relationship between the well density/proximity score and the likelihood of the baby having a congenital heart defect. The more wells there were in close proximity to the baby during prenatal development, the more likely the baby was to have a heart defect. In our research we found that 27 of the chemicals in the Garfield County air samples affect the cardiovascular system.

29. I believe this study, by itself, is not enough evidence to attribute a particular child's condition to natural gas operations. But it is enough evidence to warrant further investigation, and caution, with respect to limiting exposure and controlling overall population risk.

30. I have reviewed other studies to determine whether distance from natural gas operations mattered in terms of adverse health impacts. In particular, I read a study titled "Human health risk assessment of air emissions from development of unconventional natural gas resources" (McKenzie *et al.*, 2012). The study is reliable and authoritative on health impacts from air emissions from natural gas operations, including fracking.

31. The 2012 McKenzie study, based on risk assessment estimates, demonstrated that residents living less than half a mile from wells are at greater risk of experiencing health effects than those living further away. I concluded that distance does appear to matter with regard to the potential danger to humans from exposure to these chemicals.

32. I find another paper by the same group of researchers that published the McKenzie study to also be reliable and authoritative on the subjects it addresses. This paper was published in 2013 by Witter *et al.* It identified possible and probable health effects from air emissions associated with gas development. Specifically, the study identified cancer, birth defects, and exacerbation of chronic diseases like asthma, chronic obstructive pulmonary disease, and cardiac disease as possible long term health effects. The paper also identified more immediate, probable health effects from air emissions, including headaches and other neurological symptoms, airway and mucous membrane irritation. In other words, evidence suggests that people exposed to chemicals from natural gas development will probably experience these effects.

33. The Witter paper also cited symptoms reported in the Oil and Gas Conservation Commission's inspection/incident database. These were reported by residents living within half a mile of well development. They included headaches, nausea, upper respiratory irritation, and nosebleeds. The findings of both the Witter and McKenzie studies were consistent with the work TEDX has performed and the outcomes we have described.

34. Symptoms like those found in the studies described above can have a major impact on quality of life.

35. In my opinion, state government agencies are not doing enough to protect public health and the environment from the impacts of oil and gas development, particularly fracking. Local communities have been forced to take matters into their own hands to protect the health, safety, and welfare of their citizens and the local environment. At a minimum, routine monitoring of air emissions should be conducted at the well pad and surrounding area, as well as all other production facilities including compressors,

6

processing stations and major pipeline junctures. Monitoring should begin prior to well development (baseline), be conducted frequently, and sample a wide range of chemicals such as those reported in this affidavit (not just methane). Disclosure of all chemicals used above and below ground during drilling, fracking and production should be required. Setbacks from human activity should be large enough to be protective of exposure to air emissions, at least half a mile based on current research. Best management practices, those that fully protect citizens from exposure, should be required before further oil and gas development is allowed to occur. If the state government is not able to place the health of citizens above financial gain or other goals, local governments should have the right to do so.

I declare under penalty of perjury that the foregoing is true and correct to the best of my knowledge, information, and belief.

Carol Kwiatkowski

Carol Kwiatkowski

Date: May 21, 2014

NOTARY STATEMENT

Subscribed and affirmed before me, a notary public, this 21st day of May, 2014, in the county of Weld, State of Colorado. The above signed personally appeared and has proven to be the person whose name is subscribed to the within instrument.

Amber Voight-Byers

Signature of Notary (Seal on page)

AMBER VOIGHT-BYERS
NOTARY PUBLIC
STATE OF COLORADO
My Commission Expires 10/25/2014

Commission expires: 10/25/2014

7

Curriculum Vitae

Carol F. Kwiatkowski
carolkw@tds.net

Positions

2008-present **Executive Director,** TEDX, The Endocrine Disruption Exchange, Paonia Colorado.

2007-2008 **Senior Research Associate**, TEDX, The Endocrine Disruption Exchange, Paonia Colorado.

2004-2006 **Assistant Clinical Professor**, Project Safe, Department of Psychiatry, University of Colorado Health Sciences Center, Denver, Colorado

1999-2001 **Assistant Professor,** Project Safe, Department of Psychiatry, University of Colorado Health Sciences Center, Denver, Colorado

1996-1999 **Senior Research Associate**, Project Safe, Department of Psychiatry, University of Colorado Health Sciences Center, Denver, Colorado.

1995-1997 **Instructor**, Department of Psychology, University of Colorado at Denver, Denver, Colorado

1995-1996 **Research Analyst/Statistician**, US WEST Market Information Products, Englewood, Colorado

1991-1995 **Statistical Analyst/Programmer**, Homelessness Research Center, Department of Psychology, University of Denver, Denver, Colorado

Education

1995 Ph.D., Experimental Cognitive Psychology, University of Denver, Denver, CO

1993 M.A., Experimental Cognitive Psychology, University of Denver, Denver, CO

1988 B.A., Psychology, College of William and Mary, Williamsburg, VA

Publications

Colborn T, Schultz K, Herrick L, and **Kwiatkowski** C. 2012 (in press). An exploratory study of air quality near natural gas operations. The International Journal of Human and Ecological Risk Assessment.

Colborn T, **Kwiatkowski** C, Schultz K, and Bachran M. 2011. Natural gas operations from a public health perspective. The International Journal of Human and Ecological Risk Assessment. 17(5):1039-56.

Booth RE, Lehman WEK, **Kwiatkowski** CF, Brewster JT, Sinitsyna L, Dvoryak S. Stimulant injectors in Ukraine: The next wave of the epidemic? AIDS and Behavior 2008.

Booth RE, **Kwiatkowski** CF, Mikulich-Gilbertson, Brewster JT, et al. Predictors of risky needle use following interventions with drug injectors in Ukraine. Drug and Alcohol Dependence. 2006;82(1):S49-55.

Booth RE, **Kwiatkowski** CF, Brewster JT, et al. Predictors of HIV sero-status among drug injectors at three Ukraine sites. AIDS. 2006;20:2217-2223.

Corsi KF, Van Hunnik, BA, **Kwiatkowski** CF, Booth RE. Computerized tracking and follow-up techniques in longitudinal research with drug users. Health Services Outcomes research Methods, 2006;6:101-110.

Corsi KF, **Kwiatkowski** CF, Booth RE. Long-term predictors of HIV risk behaviors among IDUs. Journal of Drug Issues. 2006;36(3):649-666.

Kwiatkowski CF, Booth RE. HIV Risk Behaviors Among Older American Drug Users. Journal of the Acquired Immune Deficiency Syndromes. 2003;33 (Supp 2):S131-S138.

Kwiatkowski CF, Corsi KF, Booth RE. The association between knowledge of hepatitis C virus status and risk behaviors in injection drug users. Addiction, 2002;97,1289-1294.

Corsi KF, **Kwiatkowski** CF, Booth RE. Predictors of positive outcomes for out-of-treatment opiate injectors recruited into methadone maintenance through street outreach. Journal of Drug Issues, 2002; Summer:999-1016.

Kwiatkowski CF, Booth RE. Methadone maintenance as effective HIV risk reduction with street-recruited injection drug users. JAIDS, 2001;26:483-489.

John D, **Kwiatkowski** CF, Booth RE. Differences between out-of-treatment drug injectors who use stimulants only, opiates only or both: psychological symptoms and implications for treatment. Drug and Alcohol Dependence, 2001;64:165-172.

Kwiatkowski CF, Booth RE. Differences in HIV risk behaviors among women who exchange sex for drugs, money or both drugs and money. Aids and Behavior, 2000;4:233-240.

Kwiatkowski CF, Booth RE, Lloyd L. The effects of offering free treatment to street-recruited injection opiate users. Addiction, 2000; 95(5), 697-704.

Booth RE, **Kwiatkowski** CF, Chitwood DD. Sex related HIV risk behaviors: Differential risks among injection drug users, crack smokers, and injection drug users who smoke crack. Drug and Alcohol Dependence, 2000; 58:219-226.

Stephens RC, **Kwiatkowski** CF, Booth RE. The Impact of the NIDA Cooperative Agreement Programs on HIV Risk Among Crack and Injection Drug Users. In Advances in Medical Sociology: Emergent Issues in the Field of Drug Abuse, Vol 7. Eds: JA Levy, RC Stephens, DC McBride, Stamford, CT: JAI Press, 2000.

Kwiatkowski CF, Stober DR, Booth RE, Zhang Y. Predictors of increased condom use following HIV intervention with heterosexually active drug users. Drug and Alcohol Dependence, 1999;54:57-62.

Booth RE, Zhang Y, **Kwiatkowski** CF. The challenge of changing drug and sex risk behaviors of runaway and homeless adolescents. Child Abuse and Neglect, 1999;23:1295-1306.

Booth RE, **Kwiatkowski** CF, Weissman G. Health-Related service utilization and HIV risk behaviors among HIV infected injection drug users and crack smokers. Drug and Alcohol Dependence, 1999;55:69-78.

Booth RE, **Kwiatkowski** CF. Substance abuse treatment for high-risk adolescents. Current Psychiatry Reports, 1999;1:185-190.

Kwiatkowski CF, Booth RE. HIV seropositive drug users and unprotected sex. AIDS and Behavior. 1998;2(2):151-159.

Booth RE, **Kwiatkowski** CF, Iguchi MY, Pinto D, John D. Facilitating treatment entry among out-of-treatment injection drug users. Public Health Reports. 1998;113 (Supplement 1):1-13.

Booth RE, **Kwiatkowski** CF, Stephens RC. Effectiveness of HIV/AIDS interventions for out-of-treatment injection drug users. Journal of Psychoactive Drugs, 1998;30:269-278.

Braucht GN, Reichardt CS, Geissler LJ, Bormann CA, **Kwiatkowski** CF, Kirby MW. Effective services for homeless substance abusers. Journal of Addictive Diseases. 1995;14(4):87-109.

Geissler LJ, Bormann CA, **Kwiatkowski** CF, Braucht GN, Reichardt CS. Women, homelessness and substance abuse: Moving beyond the stereotypes. Psychology of Women Quarterly. 1995;19:65-83.

Human and Ecological Risk Assessment, 17: 1039–1056, 2011

ISSN: 1080-7039 print / 1549-7860 online
DOI: 10.1080/10807039.2011.605662

Hazard Assessment Articles

Natural Gas Operations from a Public Health Perspective

Theo Colborn, Carol Kwiatkowski, Kim Schultz, and Mary Bachran
TEDX, The Endocrine Disruption Exchange, Paonia, CO, USA

ABSTRACT

The technology to recover natural gas depends on undisclosed types and amounts of toxic chemicals. A list of 944 products containing 632 chemicals used during natural gas operations was compiled. Literature searches were conducted to determine potential health effects of the 353 chemicals identified by Chemical Abstract Service (CAS) numbers. More than 75% of the chemicals could affect the skin, eyes, and other sensory organs, and the respiratory and gastrointestinal systems. Approximately 40–50% could affect the brain/nervous system, immune and cardiovascular systems, and the kidneys; 37% could affect the endocrine system; and 25% could cause cancer and mutations. These results indicate that many chemicals used during the fracturing and drilling stages of gas operations may have long-term health effects that are not immediately expressed. In addition, an example was provided of waste evaporation pit residuals that contained numerous chemicals on the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and Emergency Planning and Community Right-to-Know Act (EPCRA) lists of hazardous substances. The discussion highlights the difficulty of developing effective water quality monitoring programs. To protect public health we recommend full disclosure of the contents of all products, extensive air and water monitoring, coordinated environmental/human health studies, and regulation of fracturing under the U.S. Safe Drinking Water Act.

Key Words: drilling, health, hydraulic fracturing, natural gas, ozone, pollution.

INTRODUCTION

Over the past two decades, in an effort to reduce dependence on imported fossil fuels, the U.S. government has supported increased exploration and production of

Received 8 June 2010; revised manuscript accepted 4 September 2010.
USEPA makes no claims regarding the accuracy or completeness of the information in this article. Competing interest declaration: The authors have no conflicts of interest.
Address correspondence to Theo Colborn, TEDX, P.O. Box 1407, Paonia, CO 81428, USA. E-mail: Colborn@tds.net

natural gas. The responsibility for overseeing the nation's underground minerals lies with the U.S. Department of Interior, Bureau of Land Management (BLM) with some oversight from the U.S. Environmental Protection Agency (USEPA). Attempting to meet the government's need for energy self-sufficiency, the BLM has auctioned off thousands of mineral leases and issued permits to drill across vast acreages in the U.S. Rocky Mountain West. Since 2003, natural gas operations have increased substantially, with annual permits in Colorado alone increasing from 2,249 to 8,027 in 2008 (Colorado Oil and Gas Conservation Commission 2010).

In tandem with federal support for increased leasing, legislative efforts have granted exclusions and exemptions for oil and gas exploration and production from a number of federal environmental statutes, including the Clean Water Act, the Clean Air Act, the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA, better known as the Superfund Act), the Resource Conservation and Recovery Act (RCRA), the Toxic Release Inventory under the Emergency Planning and Community Right-to-Know Act (EPCRA), and the National Environmental Policy Act (NEPA) (Oil and Gas Accountability Project 2007). The most recent of these efforts was an amendment included in the 2005 Energy Policy Act that prevented the use of the Safe Drinking Water Act to regulate certain activities, known as hydraulic fracturing, which are involved in 90% of natural gas drilling.

The cumulative effect of these exemptions and exclusions has been to create a federal void in environmental authority over natural gas operations, leaving the responsibility primarily up to the states. Although some states have oil and gas commissions to watch over natural gas production activity, the primary mission of these agencies has been to facilitate natural gas extraction and increase revenues for the states. In addition, when states issue permits to drill, they have not traditionally required an accounting of how the resulting liquid and solid waste would be handled. In short, their focus has not typically been on health and the environment.

The Need for Chemicals

In keeping with the rush to produce more natural gas, technological advances have permitted the industry to drill deeper and expand wider, tapping into gas reserves with greater facility and profitability. While these advances have allowed the mining of vast, newly discovered gas deposits, the new technology depends heavily on the use of undisclosed types and amounts of toxic chemicals.

Chemicals are used throughout operations to reach and release natural gas. First, combinations of chemicals are added to the "muds" used to drill the bore hole. Chemicals are added to increase the density and weight of the fluids in order to facilitate boring, to reduce friction, to facilitate the return of drilling detritus to the surface, to shorten drilling time, and to reduce accidents. After drilling, hydraulic fracturing (also known as fracking, frac'ing, or stimulation) is done to break up the zone in which the gas is trapped and make it easier for the gas to escape, increasing a well's productivity. In the U.S. West, approximately a million or more gallons of fluid containing toxic chemicals are injected underground during this operational stage. As with drilling, chemicals are used in fracking fluids for many purposes (Table 1). One well can be fracked 10 or more times and there can be up to 30 wells on one pad. An estimated 10% to 90% of the fracking fluid is returned to the surface during

Table 1. Functional categories of hydraulic fracturing chemicals.

Acids	To achieve greater injection ability or penetration and later to dissolve minerals and clays to reduce clogging, allowing gas to flow to the surface.
Biocides	To prevent bacteria that can produce acids that erode pipes and fittings and break down gellants that ensure that fluid viscosity and proppant transport are maintained. Biocides can produce hydrogen sulfide (H2S) a very toxic gas that smells like rotten eggs.
Breakers	To allow the breakdown of gellants used to carry the proppant, added near the end of the fracking sequence to enhance flowback.
Clay stabilizers	To create a fluid barrier to prevent mobilization of clays, which can plug fractures.
Corrosion inhibitors	To reduce the potential for rusting in pipes and casings.
Crosslinkers	To thicken fluids often with metallic salts in order to increase viscosity and proppant transport.
Defoamers	To reduce foaming after it is no longer needed in order to lower surface tension and allow trapped gas to escape.
Foamers	To increase carrying-capacity while transporting proppants and decreasing the overall volume of fluid needed.
Friction reducers	To make water slick and minimize the friction created under high pressure and to increase the rate and efficiency of moving the fracking fluid.
Gellants	To increase viscosity and suspend sand during proppant transport.
pH control	To maintain the pH at various stages using buffers to ensure maximum effectiveness of various additives.
Proppants	To hold fissures open, allowing gas to flow out of the cracked formation, usually composed of sand and occasionally glass beads.
Scale control	To prevent build up of mineral scale that can block fluid and gas passage through the pipes.
Surfactants	To decrease liquid surface tension and improve fluid passage through pipes in either direction.

well completion and subsequent production (BC Oil and Gas Commission 2010; New York State Department of Environmental Conservation Division of Mineral Resources 2009), bringing with it toxic gasses, liquids, and solid material that are naturally present in underground oil and gas deposits. Under some circumstances, none of the injected fluid is recovered.

In most regions of the country, raw natural gas comes out of the well along with water, various liquid hydrocarbons including benzene, toluene, ethylbenzene, and xylene (as a group, called BTEX), hydrogen sulfide (H_2S), and numerous other organic compounds that have to be removed from the gas. When the gas leaves the well it is passed through units called heater treaters that are filled with triethylene glycol and/or ethylene glycol that absorbs the water from the gas. Once the glycol solution becomes saturated with water, the heaters turn on and raise the temperature enough to boil off the water, which is vented through a closed system

and upon cooling, ends up in a nearby tank labeled "produced water." The glycol fluid, which has a higher boiling point than water, cools and is reused. During the heating process at critical temperatures the oily substances that came up with the gas become volatile and then re-condense into a separate holding tank. This is known as "condensate" water. The contaminated water can be re-injected underground on the well pad or off site, common practices in the eastern United States, or hauled off the well pad to waste evaporation pits in the U.S. West. Temporary pits are also constructed during drilling to hold the cuttings, used drilling mud which is often re-used, and any other contaminated water that comes to the surface while drilling. These reserve pits on well pads are supposed to be drained and covered with top soil or other suitable material within a month after drilling stops.

An Unexpected Side Effect: Air Pollution

In addition to the land and water contamination issues, at each stage of production and delivery tons of toxic volatile compounds (VOCs), including BETX, other hydrocarbons, and fugitive natural gas (methane), can escape and mix with nitrogen oxides (NOx) from the exhaust of diesel-fueled, mobile, and stationary equipment, to produce ground-level ozone (CH2MHILL 2007; Colorado Department of Public Health and Environment [CDPHE] 2007; URS 2008; U.S. Congress, Office of Technology Assessment 1989). One highly reactive molecule of ground level ozone can burn the deep alveolar tissue in the lungs, causing it to age prematurely. Chronic exposure can lead to asthma and chronic obstructive pulmonary disease (COPD), and is particularly damaging to children, active young adults who spend time outdoors, and the aged (Islam *et al.* 2007; Tager *et al.* 2005; Triche *et al.* 2006). Ozone combined with particulate matter less than 2.5 micrometers produces smog (haze) that has been demonstrated to be harmful to humans as measured by emergency room admissions during periods of elevation (Peng *et al.* 2009). Gas field ozone has created a previously unrecognized air pollution problem in rural areas, similar to that found in large urban areas, and can spread up to 200 miles beyond the immediate region where gas is being produced (U.S. Congress, Office of Technology Assessment 1989; Roberts 2008). Ozone not only causes irreversible damage to the lungs, it is similarly damaging to conifers, aspen, forage, alfalfa, and other crops commonly grown in the western United States (Booker *et al.* 2009; Reich 1987; U.S. Congress, Office of Technology Assessment 1989). Adding to this air pollution is the dust created by fleets of diesel trucks working around the clock hauling the constantly accumulating condensate and produced water to large waste facility evaporation pits on unpaved roads. Trucks are also used to haul the millions of gallons of water from the source to the well pad.

PROJECT DESIGN

The following project grew from a year 2004 request by OGAP (Oil and Gas Accountability Project) to TEDX (The Endocrine Disruption Exchange) to explore the potential health effects of chemicals used during drilling, fracking, processing, and delivery of natural gas. OGAP, a project of Earthworks, is a national non-profit

organization established in 1999 to watchdog the oil and natural gas industry. TEDX is a non-profit organization dedicated to compiling and disseminating technical information on chemicals that affect health and the environment.

Data Sources

In order to find out what chemicals were being used to extract natural gas, we took advantage of the information on the Material Safety Data Sheets (MSDSs) that accompany each product used during natural gas operations. MSDSs detailing specific products in use were provided by multiple sources including the BLM, U.S. Forest Service, state government departments, and the natural gas industry. MSDSs are designed to inform those who handle, ship, and use products that contain dangerous chemicals. They provide information about the physical and chemical characteristics of the chemicals in a product, and the immediate and chronic health effects, in order to prevent injury while working with the products. They are also designed to inform emergency response crews in case of accidents or spills. In addition to the MSDSs, we also used State Tier II Reports that must be filed by storage facilities under EPCRA. This Act sets a minimum amount above which a product that contains a hazardous substance in a storage facility has to be reported. We also supplemented our analysis with product information from disclosures in Environmental Impact Statements, Environmental Assessment Statements, and accident and spill reports. At first we looked only at what was taking place in Colorado and over the course of several years we acquired information from Wyoming, New Mexico, Texas, Washington, Montana, Pennsylvania, and New York. The list of products and chemicals quickly grew, making it apparent that hundreds of different products serving many purposes were being used in natural gas operations across the country. The number of chemical products manufacturers has also grown, making this a highly competitive industry.

It should be clear that our list of products is not complete, but represents only products and chemicals that we were able to identify, through a variety of sources, as being used by industry during natural gas operations. For most products, we cannot definitively say whether they were used during drilling or during fracking. However, an accidental blow-out of the Crosby well in Wyoming provided a unique opportunity to analyze the chemicals used during drilling, as fracking had not yet begun on that well. When the blow-out occurred, methane and other gases, petroleum condensates, and drilling fluids (muds) were released from fissures in the ground adjacent to the well. During the 58 hours the eruption took place, 25,000 square feet of soil surface in the area were contaminated. The driller released copies of the MSDSs for the products used during the blow-out and later we found the names of several more products from remedial action work plans to clean up the site (Terracon 2007).

On another occasion we were provided data from a 2007 New Mexico study, sponsored by 19 oil and gas companies and conducted by a third party consultant and analytical laboratory. This gave us the opportunity to explore the health effects of chemicals in samples of pit solids drawn from six evaporation pits where gas operations were ceasing.