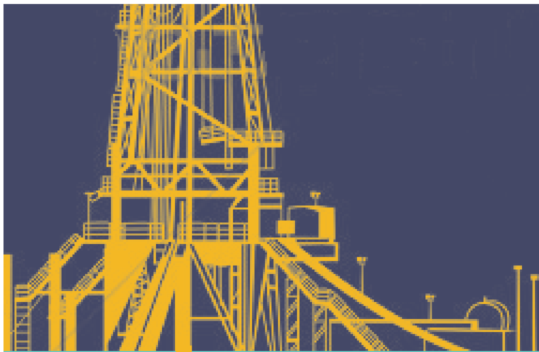

UNIVERSITY OF MICHIGAN

Public Health Technical Report

HYDRAULIC FRACTURING IN THE STATE OF MICHIGAN

ABOUT THIS REPORT

This document is one of the seven technical reports completed for the **Hydraulic Fracturing in Michigan Integrated Assessment** conducted by the University of Michigan. During the initial phase of the project, seven faculty-led and student-staffed teams focused on the following topics: **Technology**, **Geology/Hydrogeology**, **Environment/Ecology**, **Human Health**, **Policy/Law**, **Economics**, and **Public Perceptions**. These reports were prepared to provide a solid foundation of information on the topic for decision makers and stakeholders and to help inform the Integrated Assessment, which will focus on the analysis of policy options. The reports were informed by comments from (but do not necessarily reflect the views of) the **Integrated Assessment Steering Committee**, expert peer reviewers, and numerous public comments. Upon completion of the peer review process, final decisions regarding the content of the reports were determined by the faculty authors in consultation with the peer review editor. These reports should not be characterized or cited as final products of the Integrated Assessment.

The reports cover a broad range of topics related to hydraulic fracturing in Michigan. In some cases, the authors determined that a general discussion of oil and gas development is important to provide a framing for a more specific discussion of hydraulic fracturing. The reports address common hydraulic fracturing (HF) as meaning use of hydraulic fracturing methods regardless of well depth, fluid volume, or orientation of the well (whether vertical, directional, or horizontal). HF has been used in thousands of wells throughout Michigan over the past several decades. Most of those wells have been shallower, vertical wells using approximately 50,000 gallons of water; however, some have been deeper and some have been directional or horizontal wells. The reports also address the relatively newer high volume hydraulic fracturing (HVHF) methods typically used in conjunction with directional or horizontal drilling. An HVHF well is defined by the State of Michigan as one that is intended to use a total of more than 100,000 gallons of hydraulic fracturing fluid. The reports indicate if the text is addressing oil and gas development in general, HF, or HVHF.

Finally, material in the technical reports should be understood as providing a thorough hazard identification for hydraulic fracturing, and when appropriate, a prioritization according to likelihood of occurrence. The reports do not provide a scientific risk assessment for aspects of hydraulic fracturing.

Participating University of Michigan Units

Graham Sustainability Institute
Erb Institute for Global Sustainable Enterprise
Risk Science Center
University of Michigan Energy Institute

GRAHAM SUSTAINABILITY INSTITUTE INTEGRATED ASSESSMENT REPORT SERIES
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HYDRAULIC FRACTURING IN THE STATE OF MICHIGAN

Public Health and Hydraulic Fracturing in Michigan

SEPTEMBER 3, 2013

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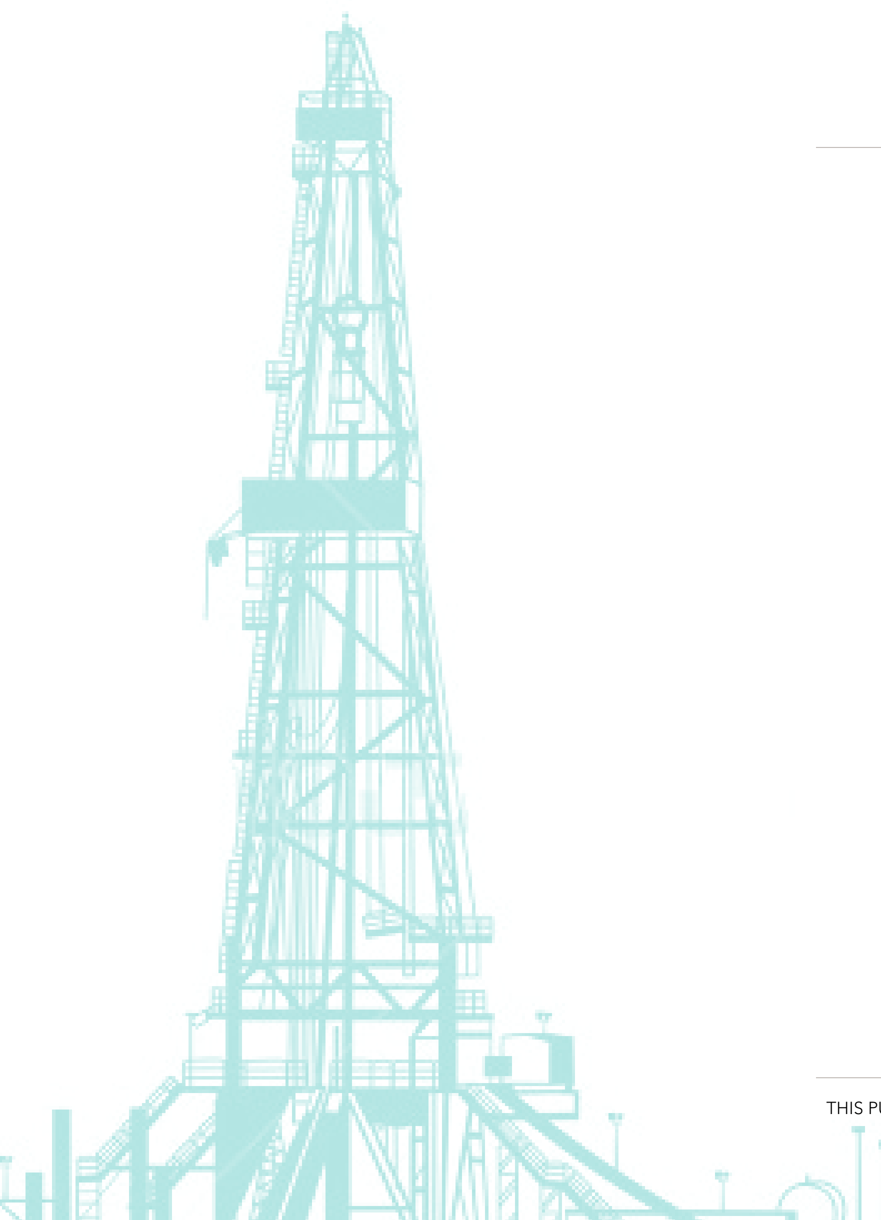

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EXECUTIVE SUMMARY

Overview

The purpose of this report is to document and discuss public health issues related to hydraulic fracturing in the State of Michigan. As a report focused on public health, it is guided by the definition put forth by the American Schools of Public Health, which states that public health is "the science and art of protecting and improving the health of communities through education, promotion of healthy lifestyles, and research for disease and injury prevention… public health works to prevent health problems before they occur". Therefore, this report is concerned with potential hazards that are not only chemical (i.e., toxicants) but also those that are physical, biological, and psychosocial. In many ways, this report may be considered a hazard identification piece. While a number of hazards have been identified, largely from studies performed outside of Michigan, there exists limited data linking these hazards with human exposures, thus limiting the opportunity to conduct a risk assessment.

This report is focused on reviewing public health risks and benefits in three primary environments: 1) the hydraulic fracturing workplace; 2) the ecological environments that surround facilities; and 3) the communities that are situated near facilities. For each of these three settings, a number of potential hazards are identified, pertinent human exposure routes are described, and associated human health effects are listed. Possible hazards in the workplace include accidents and injuries, exposure to excessive noise and inadequate lighting conditions, exposures to silica and industrial chemicals, and shift or night work. Possible hazards in the surrounding environment include impaired local and regional air quality, water pollution, and degradation of ecosystem services. Possible hazards in nearby communities include increased traffic and motor vehicle accidents, stress related to risk perception amongst residents, and boomtown-associated effects such as a strained healthcare system and road degradation. Public health benefits exist, and these may include improved economic conditions in communities and energy or pollution tradeoffs related to a shift away from coal and oil. The risks and benefits can vary from local to global scales.

Key Challenges and Opportunities

The greatest challenge to understanding the potential public health risks of hydraulic fracturing in Michigan is the lack of State-specific data. While thousands of wells in Michigan have been produced (or are currently in production), the potential public health risks related to these facilities have been poorly documented. Further, most of these are not considered high-volume operations. The lack of objective, scientific-data specifically from Michigan related to high-volume hydraulic fracturing provides a challenge for local risk assessors and decision makers.

Another challenge in any human health study is related to epidemiological causation. Even if a hazard is identified at a hydraulic fracturing facility, linking it to an adverse health outcome through an exposure-disease model requires carefully designed epidemiological studies that include, for example, a robust sample size, state-of-the art exposure assessments, an appropriate control population, temporal sampling to assess potential latent effects, and consideration of cumulative impacts from multiple stressors. Ideally, these efforts would already be underway given the extent of existing hydraulic fracturing in the State. One major criticism of risk assessments from other States concerns a lack of pre-fracturing, baseline data. Baseline data is needed in order to discern whether or not hydraulic fracturing operations are causing health impacts on workers, ecosystems, or communities. Timely action towards gathering baseline public health data may allow Michigan the opportunity to overcome challenges faced in other states related to poor or missing data.

There has been some disclosure of the chemicals used at hydraulic fracturing sites in Michigan, perhaps representing a small sample of Michigan-specific data. However, this disclosure is minimal, with only a few facilities reporting upon a small number of drilling events. In addition, the disclosed information does not include data regarding the amount of chemicals used. Thus, it is of limited use in evaluating potential risks and weighing them against potential benefits.

A survey of Michigan residents found that a majority of respondents have heard about hydraulic fracturing, and that many (45%) had a negative reaction to the term 'fracking'. However, more than 50% of respondents believe natural gas drilling will provide more benefits to the State, and more than 50% either 'strongly' or 'somewhat' support the activity. The lack of objective, science-based evidence may be leading to skewed risk perceptions and debate among stakeholders.

Any public health assessment of hydraulic fracturing in Michigan needs to be conducted with careful consideration of other energy sources, relative tradeoffs, and associated public health risks and benefits. These risks and benefits will vary from the local to regional/state, national, and global levels.

Proposed Prioritized Pathways for Phase 2

- A need for Michigan-specific public health data that ranges from the health of workers to ecosystems to communities.
- There is a need to increase understanding of the fluids used in the hydraulic fracturing process, such as which chemicals are used, their exact volumes, recoveries at different stages of extraction and associated processes, disposal, etc.

- Public health education and outreach to increase understanding by stakeholders.
- Consideration of the risks-benefits of hydraulic fracturing in Michigan versus other energy sources, in terms of both health outcomes and economic value.

1.0 INTRODUCTION

1.1 Background

Hydraulic fracturing is growing rapidly across many regions of the United States and worldwide[1]. While the rate of hydraulic fracturing development in Michigan is not as great as other States, as elaborated by Wilson and Schwank[2], Michigan has long been known to have plentiful natural gas reserves. These reserves are largely in the Antrim Shale, though with increased geochemical knowledge and newer technologies there has been interest in deeper reserves situated within the Utica and Collingwood Shales (Figure 1). As discussed by both Wilson and Schwank (2013) and Zullo and Zhang (2013) in this series, it is currently not economically feasible to develop these deeper shale gas reserves, though increases in the price of natural gas could change this. More than 12,000 wells have been hydraulically fractured in Michigan[3]. Most of these have been shallow, vertical hydraulic fractures, requiring relatively low volumes of hydraulic fracturing fluid[4]. Stimulation of such reserves is not new, but rather, the activity in certain regions has increased in recent years because new technologies (e.g., horizontal or directional drilling, multi-stage platforms) have become available and proven to increase extraction, enabling production of previously inaccessible natural gas reserves in an unconventional manner. Furthermore, hydraulic fracturing is being hailed as an activity that will help grow the economy, create jobs, and lessen the dependency upon foreign energy suppliers.

Hydraulic fracturing using high volumes of water and new technologies has proliferated in recent years, though there exists a dearth of knowledge concerning its public health impacts[5]. Much of the public health information available is based on anecdotes and non-peer-reviewed science. There are some emerging peer-reviewed publications and a number of active studies being pursued by governmental and non-governmental agencies, industry, and academics. Thus, in coming years the outputs of these studies will be important to risk assessors and decision makers.

1.2 Objective

The purpose of this report is to document and discuss public health issues concerning hydraulic fracturing in the State of Michigan. In doing so, it is guided by core principles in public health and human health risk assessment, both of which are briefly reviewed below. Given that hydraulic fracturing in Michigan consists of both high-volume and lower volume operations, and that at this

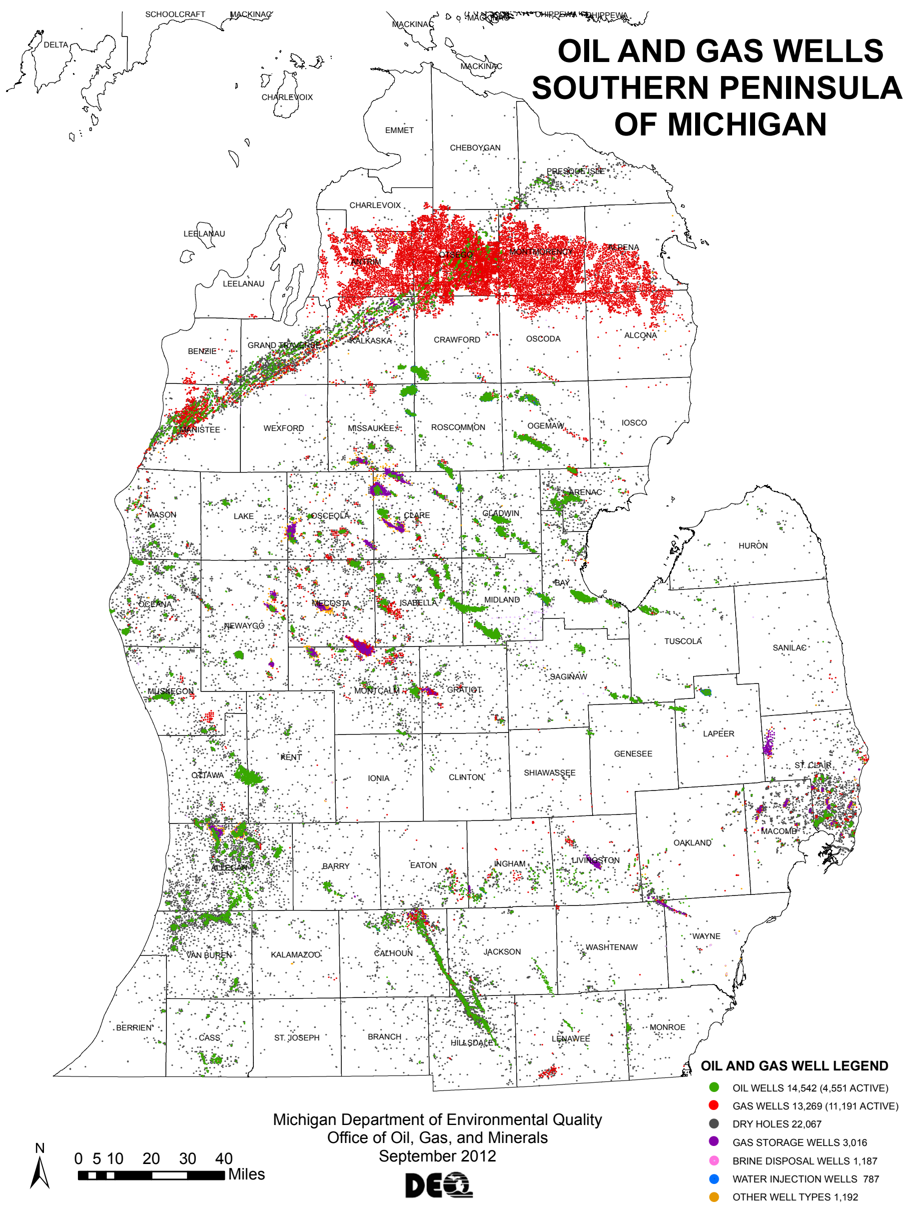


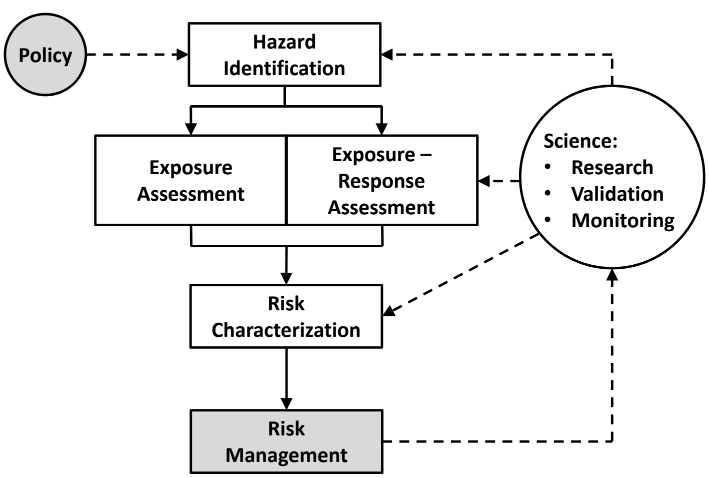
Figure 1: Oil and gas wells in the Lower Peninsula of Michigan. Source: Michigan Department of Environmental Quality.

stage we cannot necessarily discriminate between them in terms of public health relevant data, this paper aims to discuss the issue in broader terms.

Public health is concerned with preventing illness and improving the health of populations. The American Schools of Public Health (ASPH) describes public health as "the science and art of protecting and improving the health of communities through education, promotion of healthy lifestyles, and research for disease and injury prevention… public health works to prevent health problems before they occur"[6]. The view from the World Health Organization, "a state of complete physical, mental and social well-being, and not merely the absence of disease or infirmary", is also comprehensive[7]. Therefore, a public health assessment of hydraulic fracturing in Michigan needs to be inclusive and holistic, and consider a range of disciplines including occupational safety and health, air and water quality, public perceptions, and health economics.

Risk assessment aims to estimate the nature and probability of adverse human health effects[8] (Figure 2). The first step is Hazard Identification, which aims to identify potential threats and to qualitatively address any adverse consequences associated with these threats. It is important to note that hazard and risk are not equivalent terms; hazard refers to a broadly defined agent that could potentially cause harm, while risk refers to the probability of that agent actually causing harm. Exposure Assessment aims to quantify hazard exposure for individuals. Dose-Response Assessment aims to link an exposure or dose with the probability of an effect. The information gathered via Hazard Identification, Exposure Assessments, and Dose-Response Assessment is used to characterize risk and eventually make management decisions.

Figure 2: Key steps in human health risk assessment.



As elaborated in the next section, substantial data gaps exist for hydraulic fracturing in the State of Michigan, thus a majority of this report may be considered Hazard Identification. This report is concerned with potential hazards that are not only chemical (i.e., toxicants) but also those that are physical, biological, and psychosocial. For organizational purposes, the report is broadly separated into hazards found primarily in the workplace (Part 2), the surrounding environment (Part 3), and in nearby communities (Part 4). In reality, the same hazard may exist in different environments, and hazards from one environment may interact with a hazard from another environment. It is also important to realize that despite a long history of hydraulic fracturing in the State of Michigan, most of this activity has occurred with low volumes of water and via vertical drilling (compared to the high-volume, horizontal drilling that is of contemporary concern). As such, this report does not necessarily focus on potential public health impacts of one form of drilling over another, but aims to review information from both.

1.3 Limitations and Assumptions

Substantial gaps in data availability, not only in Michigan but elsewhere, prevent a full assessment of public health risks associated with hydraulic fracturing. Public policy should be grounded in strong, objective peer-reviewed science rather than anecdotes and beliefs. Speculative conclusions and opinions about possible hazards based solely upon anecdotes and oversimplified chronologies are not a sufficient foundation to advance state regulatory reforms or policies. Nevertheless, health concerns expressed by community members, especially those with scientific plausibility and those recurring across temporal and spatial scales need to be taken seriously. In this report, all currently available evidence was reviewed and considered.

A majority of the evidence reviewed in this report was obtained from studies undertaken in other States, and while we recognized that risks are often site-specific, for the purposes of this paper we maintain broad generalizations (for example, Table 1 provides some generalized parameters related to a typical high-volume hydraulic fracturing operation that may help orient the reader). The lack of exposure assessment information for any hydraulic fracturing site limits the ability to perform meaningful risk assessments. Therefore, the review of several hazards in this report should not lead the reader to conclude that all individuals, communities, or ecosystems associated with hydraulic fracturing are exposed to all of these hazards and are at health risk, as hazard is not the same as risk. The limited data also prevents us from adequately distinguishing between low-volume vertical wells and large-volume and/or directional drilling operations. Table 2 provides a snapshot of the public health issues covered in this report and the strength of evidence from the broader field and from Michigan specifically.

Figure 3: Report framework.

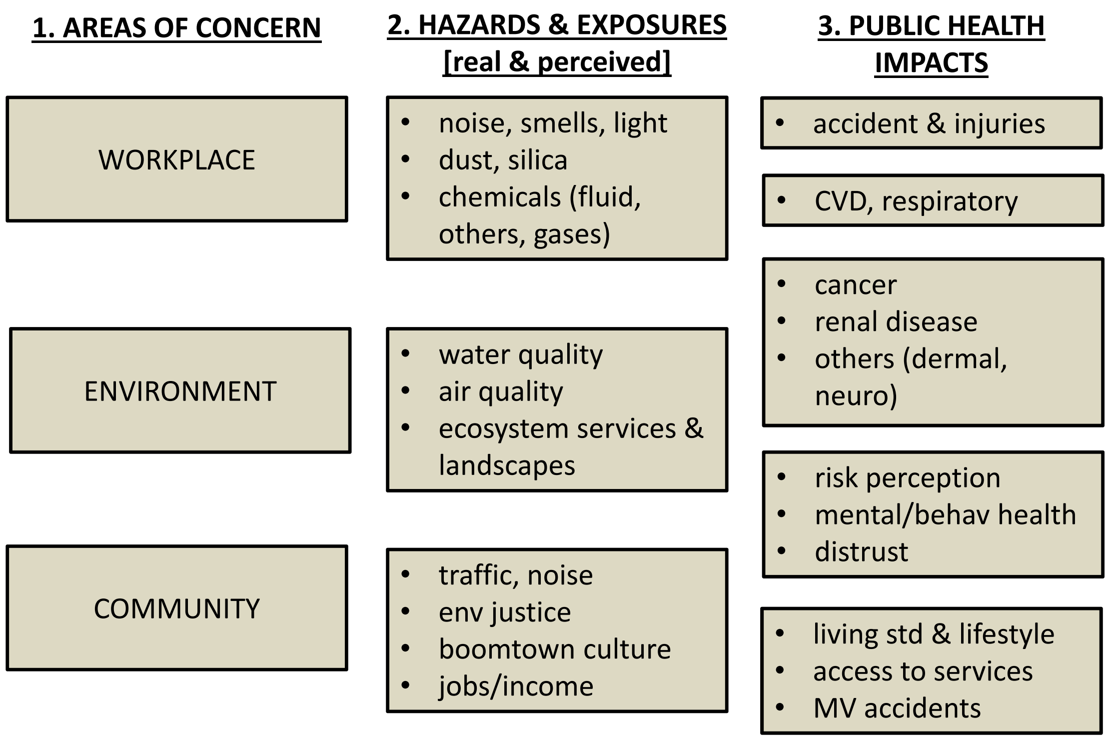


TABLE 1: Estimated base case and range values for a variety of activities related to high-volume hydraulic fracturing operations. Table modified from Jiang et al. 2011[9] and is reflective of operations in the Marcellus Shale. These numbers may not be representative of Michigan, but may serve as a basis for developing Michigan-specific numbers.

Parameter	Units	Base case	Range
Area of access road	Acres	1.43	0.1-2.75
Wells per pad	Number	6	1-16
Area of well pad	Acres	5	2-6
Vertical drilling depth	Feet	8500	7000-10,000
Horizontal drilling length	Feet	4000	2000-6000
Fracturing water	MMgal/well	4	2-6
Flowback fraction	Percent	37.5	35-40
Recycling fraction	Percent	45	30-60
Trucking distance between well site and water source	Miles	5	0-10
Trucking distance between well site and deep well injection facility	Miles	80	3-280
Well completion time with collection system in place	Hours	18	12-24
Well completion time without collection system in place	Days	9.5	4-15
Fraction of flaring	Percent	76	51-100
Initial 30 day gas flow rate	MMscf/day	4.1	0.7-10
Average well production rate	MMscf/day	0.3	0.3—10
Well lifetime	Years	25	5-25

TABLE 2: Possible public health issues related to hydraulic fracturing from Sections 2, 3, and 4 of this paper. For each, we qualitatively assessed the available evidence and scored each hazard with an "X" mark (plausibility score). "X" = hazard is plausible, anecdotes exist but no scientific studies found; "XX" = scientific evidence exists and is suggestive but also limited (e.g., few studies, poor design, confounders); "XXX" = scientific evidence exists and is strong (e.g., many studies, good design, causality). The assigned scores are based on the expert judgment of the authors. In the final column, we indicate Yes (Y) or No (N) if any anecdotes, reports, studies or datasets were found in Michigan concerning that particular hazard, but did not judge the strength of the evidence.

Issue	Paper Section	Plausibility Score	Michigan Evidence?
Injuries	2.2	XX	N
Noise	2.3	XX	Y
Light	2.4	X	N
Odor	2.5	XX	Y
Silica	2.6	XXX	Y
Intentional-Use Chemicals	2.7	XXX	Y
By-product Chemicals	2.8	XXX	Y
Transportation	3.1	XXX	N
Air Quality	3.2	XXX	N
Water Quality	3.3	XXX	N
Habitat and Wildlife Impacts	3.4	XXX	N
Food and Animal	3.5	XX	N
Earthquakes	3.6	XX	N
Public Perception	4.1	XXX	Y
Environmental Justice	4.3	XX	N
Health & Social Services	4.4.1	XX	N
Local Socio-Economics	4.4.2	XX	N
Bust or Recovery	4.4.3	XX	N

1.4 Relation to Integrated Assessment

The goal of the Integrated Assessment is to collate and analyze the environmental, social, and economic dimensions of hydraulic fracturing and its impact on Michigan communities, human health, and ecosystems. Accordingly, public health is an integral component of the overall Integrated Assessment as the scientific findings and tools of public health offer a scheme to integrate across disciplines. As this report is principally focused on identifying hazards, Phase 2 of the Integrated Assessment should consider such public health hazards (and associated risk-benefits) when addressing the question - "What are the best environmental, economic, social, and technological approaches for managing hydraulic fracturing in the State of Michigan".

2.0 THE WORKPLACE ENVIRONMENT

The occupational environment or workplace is a unique setting in public health, as it is a central environment where people may spend most of their time outside the home. In the workplace people may be chronically exposed to a diverse array of stressors, some of which can potentially occur in high concentrations[10]. Hydraulic fracturing workers are thus a sensitive sub-group in public health that warrant focused study. Given that job creation is one argument in favor of the expansion of hydraulic fracturing and natural gas production in Michigan (though Zullo and Zhang (2013) in this series indicate the validity of this claim may be questionable, particularly in relation to the benefit received by local communities), the health hazards for the workers filling those jobs should be examined to inform an assessment of occupational cost-benefits. In this section we cover what is known about the hazards that may exist in a typical hydraulic fracturing operation, and where possible, we provide information specific to Michigan. Further, some of the hazards that exist within the worksite may also extend into the nearby environment (Section 3) and communities (Section 4). For introductory purposes, Table 2 provides an estimate of parameters concerning various activities in a hydraulic fracturing site that may help orient the reader.

2.1 Employment

Any discussion of the workplace must also consider the employment landscape. This topic is covered by Zullo and Zhang (this series) and briefly mentioned here. According to the US Bureau of Labor Statistics, in August of 2012 the national rate of unemployment was 8.1%. Michigan had an even higher 2012 unemployment average of 9.4%[11]. In regions of economic decline, community members often embrace energy development efforts because of the economic benefits[12]. In October 2012, the Center for Local, State and Urban Policy (CLOSEUP) at the University of Michigan Ford School, conducted a telephone survey of 415 Michigan residents. Of those interviewed, via an open-ended question on the 'primary potential benefit of fracking', 20% were in support of hydraulic fracturing due to the industry's ability to create jobs and stimulate local investments. Further, 82% of survey respondents indicated that natural gas was 'very important' (36%) or 'somewhat important' (46%) to Michigan's economy[13]. According to a 2010 IHS Global Insight report, the hydraulic fracturing industry has created over 600,000 jobs nationwide to date[14]. This number is projected to reach 1.6 million by the year 2035. In Michigan, a 2012 IHS Global Insight report found that unconventional natural gas development accounted for 28,063 total jobs in 2010 and is projected to increase to 63,380 jobs by 2035[15].

Jobs within the hydraulic fracturing industry may fall into eight categories[13]: general services, retail and wholesale trade, transportation and utilities, manufacturing, construction, mining, agriculture, and government. The largest percentage of workers falls in the general services category, which includes an estimated 45% of the 601,348 workers nationally. The lowest categories of job creation are in government and agriculture, both estimated at about 1% of workers nationally[14]. When broken down by individual well operation, there is an average of 420 workers per location across 150 occupations. Approximately 90% of these jobs occur during the development and drilling phases of a hydraulic fracturing operation. Typically pre-drilling requires a time period of about six to nine months, with actual drilling occurring over two months[16]. Thus the vast majority of jobs associated with hydraulic fracturing operations are short-term temporary positions, but workers may move across sites and thus these positions may be longer-term.

A majority of hydraulic fracturing jobs require little post-secondary education; however, most do require experience-driven skills, unique industry related knowledge, and are highly intensive[12,16,17]. Long-term residents of rural communities often find the prerequisite drilling experience an employment barrier, and thus workers are typically brought in from outside the community to fill such positions[12]. While there is a lack of data tracking the residency of workers, many are thought to be transient or of a migrant worker population. According to a report on the history of Pennsylvania's energy industry and the 2010 census data, about 40% of drilling companies utilized non-resident, temporary employees[18]. This is especially true for the larger energy companies who hire from an international pool and have access to supply-chain services[16]. These trends can be changed if local training and education facilities were more widely available to residents of targeted natural gas rich communities[12]. It is important to also note that migrant workers may experience unique health effects[19].

2.2 Fatal and Non-Fatal Injuries and Illnesses

Occupational hazards found at a typical hydraulic fracturing operation are similar to those present at most construction sites. Notable physical hazards may include slips and falls, hand and finger injuries, muscle strains, exposure to extreme temperatures and inadequate lighting conditions, fires and explosions, and injuries caused by moving vehicles, heavy equipment, high pressure lines, pinch points, and working in confined spaces[20]. Long work hours and shift work can increase workers risk of fatigue, which can negatively affect safety and performance and lead to a number of health conditions such as cardiovascular disease and diabetes[21]. Properly training workers in the safety protocols related to each job preformed can aid in avoiding many of these hazards. Also, every worker should have the appropriate personal protective equipment for the job that they will be performing and be properly trained on how to use this equipment.

There is a lack of readily available datasets concerning rates of fatal and non-fatal accidents and injuries specific to the hydraulic fracturing industry. The U.S. Department of Labor, Bureau of Labor Statistics (BLS), reports fatal and non-fatal injuries and illnesses for the oil and gas industry as a whole, which includes natural gas extraction and hydraulic fracturing. Fatal injuries for the oil and gas industry between 2004 and 2008 ranged from 98 to 125 deaths annually. In 2008, the major causes of fatal injuries were transportation (49%), contact with objects and equipment (30%), and fires and explosions (18%)[22]. Based on BLS data, between 2003 and 2009 there were 202 motor vehicle fatalities for workers in the oil and gas sector, and the fatality rate for motor vehicle accidents is approximately 8.5-times greater than for other occupational sectors[23]. In Michigan, there were no reported fatal injuries from 2008–2011 for the mining industry, which includes oil and gas extraction[24].

In terms of non-fatal injuries, in 2011 the injury and illness rate for the oil and gas industry in the United States was 0.9 incidents per 100 workers, with over half of these incidents resulting in days spent away from work or job transfer or restriction[25]. In Michigan, the non-fatal injury and illness rate for 2011 was 1.8 incidents per 100 workers for the mining industry as a whole[24].

There are a few news reports on injuries and deaths from outside of Michigan. For example, in North Dakota a hydraulic fracturing worker was killed and another worker was injured on January 19th, 2013 at a site located north of Watford City. Reports indicate that a pipe became disconnected and fatally struck the worker in the head[26]. There have also been reports that the traumatic injury rate in the Watford City region has increased 200% since 2007 from incidents related to the hydraulic fracturing operations there[27]. Note that we were unable to find any news reports concerning accidents or injuries in Michigan.

2.3 Noise Pollution

According to a 2008 literature review done by the University of Colorado School of Public Health, there were no studies published which focused on noise pollution associated with the oil and gas industry from 2003 to 2008[28]. However, throughout the process of hydraulic fracturing there are stages in which workers and nearby communities may experience heightened noise in the area. These activities include noise from drilling, well pumps, and compressors[28]. Noise has been associated with negative health effects such as annoyance, stress, irritation, unease, fatigue, headaches, and adverse visual effects[29,30]. Due to the fact that some hydraulic fracturing operations happen 24 hours a day[31], all of the above activities also have the potential to interfere with sleep of area residents[28]. Another potential noise source is truck traffic. The New York State Department of Environmental Protection estimates that 800 - 1200 trucks are required for an individual well[32], and thus residents living closest to hauling routes, especially children and the elderly, may be particularly vulnerable to increased noise pollution exposure[33].

In Michigan, residents have complained of noise from oil and gas operations. A 2003 survey of newspaper articles and informal interviews from Manistee and Mason Counties reported complaints about constant noise, such as from routine machine operation, and sudden noise from equipment malfunction or warning devices[34]. We emphasize that this survey was not scientifically conducted or peer-reviewed, contains accounts disputed by State agencies, and does not pertain specifically to hydraulic fracturing operations. Nevertheless, we reference it here and in later sections because the anecdotal evidence may be relevant in future assessments, useful in anticipating potential issues, and pertinent to individuals' perceptions of health-related risks.

2.4 Light Pollution

Based on the Fracfocus website, during the first year (or more) of a hydraulic fracturing operation, the process can run 24 hours a day and seven days per week[35], with large industrial lights surrounding the well pad to keep it lit (note, in Michigan operations typically last 2 days in an Antrim well and up to three weeks for a deep well; Fitch and Goodheart, Michigan Department of Environmental Quality, pers. comm.). If drilling and activities occur at night, this may also cause stress and affect sleep in nearby communities. Light pollution from artificial light has become a relatively new focus of public health due to its potential connection to increased breast cancer incidence[28]. Light-at-night or LAN has been shown to decrease the production of melatonin and result in the increase of estrogen production[36]. A study conducted in 2001 found that there was a 60% increased risk for women diagnosed with breast cancer if they worked a graveyard shift, defined as working between 7:00pm and 9:00am, once in the ten years before diagnosis[37]. This becomes a health risk factor in the hydraulic fracturing industry because during early (i.e., 1-3 months) production, crews may be employed 24 hours a day[35]. On the other hand, like other construction sites there may also be concerns related to poorly lit work environments.

2.5 Chemical-Related Odor

A reported short-term effect of the hydraulic fracturing industry is a rotten egg-like odor commonly associated with odorous hydrocarbons[2,27,38]. Hydrogen sulfide (H2S) can enter the air naturally from hydraulic fracturing sites, and at low levels of concentration it has a rotten egg smell[28]. In the occurrence of a wastewater spill, Bamberger and Oswald[39] documented local families becoming sick due to chronic exposure to sewage gas. It should be noted that this evidence was based on selected interviews and that the report has come under scrutiny by others, but nonetheless relevant people were interviewed and the paper was subject to scientific peer-review.

While no odor threshold has been legally established in Michigan[40], in article R 324.1013 of Michigan's 2006 Oil and Gas Regulations, nuisance odors are to be prevented in all stages of energy related development or production. Nuisance odors are defined as any single or combination of gas, vapor, fume, or mist emission in any quantity, which cause injurious health or quality of life effects. If any facility with the presence of hydrogen sulfide receives one or more complaints about its' odor, the permittee of the facility must conduct numerical modeling in order to determine ambient air concentrations H2S. In Michigan oil and gas facilities must have H2S detection monitors, emergency breathing apparatus, and all free gas must be flared and tested for H2S[40].

No scientific or peer-reviewed studies of chemical-related odor were identified with respect to hydraulic fracturing in Michigan, but some anecdotal evidence associated with drilling has been documented. The 2003 survey of newspaper reports and interviews from Manistee and Mason Counties described reported cases between 1979 and 2002 where residents indicated detecting odors, in some instances allegedly persisting a week and causing nausea and headaches[34]. While these reports were not from high-volume hydraulic fracturing sites, it is important to anticipate and recognize that some baseline odors may exist and that these may come from various aspects of oil and gas drilling. Again, we note that this survey was not published in the scientific peer-reviewed literature.

2.6 Silica Exposure

On June 21, 2012 U.S. Department of Labor, Occupational Safety and Health Administration (OSHA) issued a hazard alert concerning the potential of hydraulic fracturing workers to be exposed to respirable crystalline silica[41]. This hazard alert was the result of a study conducted by the National Institute of Occupational Health and Safety (NIOSH), which collected a total of 116 full shift air samples from hydraulic fracturing sites in Arkansas, Colorado, North Dakota, Pennsylvania, and Texas. This research documented that 47% of the samples collected had silica levels greater than the permissible exposure limits (PEL) set by OSHA and that 79% had levels greater than the NIOSH recommended exposure limit (REL)[41]. In Michigan, to our knowledge, air samples from hydraulic fracturing sites have never been collected for the purposes of determining concentrations of silica. There is a long history of silica mining in the Upper Midwest, and dramatic increases in silica mining have occurred in both Wisconsin and Minnesota[42,43]. While there exists no Michigan data concerning airborne silica levels, disclosure information from some hydraulically fractured Michigan wells includes "MI Specific 20/40 mesh sand" and "MI Specific 40/70 mesh sand" (trade names), indicating that at least some of the silica used in hydraulic fracturing in Michigan may be sourced from Michigan[35].

The NIOSH study identified multiple sources of silica dust exposure from a typical hydraulic fracturing operation. Silica sand is used in large quantities during a hydraulic fracturing operation because it is added to hydraulic fracturing fluid as proppant. Proppants are pumped underground during hydraulic fracturing so that they become inserted into the fissures, keeping the fissure open and allowing the natural gas to flow out of the well. Large quantities of silica sand must be mixed with the hydraulic fracturing fluid. Once on site it is transferred using sand movers and conveyor belts, all of which produce silica dust. Silica dust is also produced by the heavy truck traffic that occurs at a hydraulic fracturing site. Silica exposure was shown to be the greatest for workers who serve as sand movers and blender operators, as well as individuals who may work downwind of such operations[41]. However, workers located upwind and not in the immediate vicinity of the produced silica dust were also exposed to silica, likely through the dust generated from truck traffic. The exposure of workers upwind and distant from the site raises the possibility of silica exposures for community members (Section 4) as well.

Prolonged inhalation of silica can lead to the lung disease silicosis. There are different types of silicosis, which are dependent on the amount of silica a worker is exposed to and the duration of exposure. Chronic silicosis occurs from long-term inhalation of low quantities of silica and can take 20-40 years to develop[44]. Acute and accelerated silicosis can occur in a much shorter time frame, 1-3 years, when workers are exposed to high levels of silica. Symptoms can include cough, shortness of breath, massive fibrosis, reduced lung function; silicosis can result in respiratory failure[44]. There are multiple ways to reduce the amount of silica that hydraulic fracturing workers are exposed to; these include changes to how silica is transported, added engineering controls and protective equipment, and using an alternative proppant in hydraulic fracturing fluid (though OSHA also recommends evaluation of alternative proppants for possible health effects)[41]. The 2012 OSHA Hazard Alert[41] outlines many specific steps that can be taken to reduce the amount of silica dust produced and worker exposure to silica. Silica exposure has also been related to a range of other cardiovascular and respiratory diseases.

2.7 Intentional-Use Industrial Chemicals

Workers may be exposed to a variety of industrial chemicals that are intentionally used in hydraulic fracturing. Chemicals are an integral component of the hydraulic fracturing process and perform a number of functions as summarized in Table 3.

In order to increase understanding of the potential health impacts associated with exposure to hydraulic fracturing fluids, studies have identified constituent chemicals and cross-referenced them with known or suspected health effects. The diversity of chemicals and formulations, coupled with varying site-specific factors, proves challenging when conducting risk assessments. For example, the number of different formulations (mean: 13, range: 3-37), products (mean: 226, range: 67-450), and chemicals (mean: 132, range: 61-304) reported by service companies is wide-ranging[49]. Here we briefly review two recent assessments, and also provide some data concerning chemicals disclosed to have been used in Michigan hydraulic fracturing facilities.

In 2004 a project was initiated by The Endocrine Disruption Exchange (TEDX)[50] to identify and classify chemicals used in the hydraulic fracturing industry[45]. This research identified the use of 944 products, with a total of 632 chemicals reported to be in these products. A list of the five chemicals found to be included in the greatest number of products is provided (Table 4). Of the 632 chemicals reported, 56% (or 353 chemicals) had unique Chemical Abstracts Service (CAS) numbers assigned to them. As CAS numbers identify specific chemical substances (single chemicals, mixtures, etc.) which may have many different names, chemicals without unique CAS numbers provided can be difficult or impossible to identify as specific chemical additives, posing problems for evaluation of their health effects. Next, the researchers queried each chemical with a CAS number against various databases (e.g., MSDS sheets, TOXNET) to increase understanding of plausible health effects. In doing so, more than 75% of the chemicals were shown to possibly affect the respiratory and gastrointestinal systems as well as eyes, skin, and other sensory organs. Nearly half (40-50%) of the chemicals could affect the neurological, immune, cardiovascular, and renal systems. One-quarter of the chemicals were either known, probable, or possible carcinogens. For example, benzene is a known human carcinogen and acrylamide is a probable human carcinogen. Finally, 37% of the identified chemicals could have effects on the endocrine system. The researchers also noted that 44% of the chemicals were not evaluated because they were not disclosed or they did not have adequate toxicological data.

Waxman et al.[51], via the U.S. Congressional Committee on Energy and Commerce, also conducted a study to identify and classify chemicals used in the hydraulic fracturing industry. The Committee requested 14 leading oil and gas service companies to disclose the types and volumes of products used in hydraulic fracturing between 2005 and 2009, as well as the chemical composition of those products. All companies approached voluntarily provided information. Collectively they reported using more than 2,500 products in hydraulic fracturing, and that these products contained 750 chemicals. As indicated in Table 4, methanol was found in the greatest number of products, followed by isopropanol, 2-butoxyethanol, and ethylene glycol. During the time period under investigation, these companies also reported collectively using 780 million

TABLE 3: Categories of chemicals used in hydraulic fracturing, their purposes, and an example of a commonly used chemical. Information in this Table was compiled from Colborn et al.[45], DOE report[46], Gosman et al.[47], and Encana[48].

Functional Category	Purpose	Example(s) of Chemical
Diluted acids	Improve injection and penetration; dissolve minerals and clays to minimize clogging, open pores, and aid gas flow	Hydrochloric acid
Biocide	Minimize bacterial contamination of hydrocarbons; reduce bacterial production of corrosive byproducts to maintain wellbore integrity and prevent breakdown of gellants	Glutaraldehyde
Breaker	Added near end of sequence to assist flowback from wellbore; breaks down gel polymers	Ammonium persulfate
Clay Stabilizer	Establishes fluid barrier to prevent clays in formation from swelling; keeps pores open; creates a brine carrier fluid	Potassium chloride
Corrosion Inhibitor	Maintain integrity of steel casing of wellbore by preventing corrosion of pipes and casings	N,N-dimethylformamide
Crosslinker	Thickens fluid to hold proppant	Borate salts
Defoamer	Lowers surface tension and allows gas escape	Polyglycol
Foamer	Reduces fluid volume and improves proppant carrying capacity	Acetic acid (with NH4 and NaNO2)
Friction Reducer	Improves fluid flow efficiency through wellbore by reducing friction between fluid and pipe; alleviates friction caused by high pressure conditions	Polyacrylamide
Gel/Gellant	Thickens fluid (water) to suspend proppant	Guar gum
Iron Control	Prevents materials from hardening and clogging wellbore; prevents metal oxide precipitation	Citric acid
Oxygen Scavenger	Maintains integrity of steel casing of wellbore; protects pipes from corrosion by removing oxygen from fluid	Ammonium bisulfate
pH Adjusting Agent/ Buffers	Controls pH of solution; protects pH-dependent effectiveness of other chemicals (e.g., crosslinkers)	Sodium carbonate, potassium carbonate
Proppant	Holds open (props) fractures to allow gas to escape from shale	Silica, sometimes glass beads
Scale Control	Prevents mineral scale formation which can clog wellbore, block fluid or gas flow	Ethylene glycol
Solvents	Improve fluid wettability or ability to maintain contact between the fluid and the pipes	Stoddard solvent
Surfactant	Improves fluid flow through wellbore by reducing surface tension	Isopropanol

gallons of products (not including water) in hydraulic fracturing. Of this amount, 94 million gallons of 279 products contained a component that was deemed proprietary. In some cases, but not all, this information was disclosed.

The study by Waxman et al.[51] also revealed that products used in hydraulic fracturing included 29 chemicals of concern that are known or possible carcinogens, regulated under the Safe Drinking Water Act (SDWA), or listed as hazardous pollutants under the Clean Air Act (CAA). BTEX compounds (benzene, toluene, ethylbenzene, and xylene) were included within this list of chemical components of concern and were reported to be present in 60 products. There were also notable carcinogens including diesel (51 products), naphthalene (44 products), formaldehyde (12 products), sulfuric acid (9 products), and thiourea (9 products). Ninety-five products contained 13 different carcinogens, and more than 10.2 million gallons of hydraulic fracturing products included at least one carcinogen.

The aforementioned studies conducted by Colborn et al.[45] and Waxman et al.[51] document that a large number of chemicals are used in hydraulic fracturing and that many of these chemicals have intrinsic toxic properties. We explored the FracFocus database to determine if these findings can be extended to Michigan. FracFocus is a national hydraulic fracturing chemical registry managed by the Ground Water Protection Council (a nonprofit for groundwater protection) and the Interstate Oil and Gas Compact Commission (a government agency, for oil and gas development and protection of health and the environment). More than 35,000 well sites have been registered nationally thus far, with 13 well sites in Michigan having reported data as of March 16, 2013[35]. Sometimes, a single well may need to be fractured more than once, thus requiring

TABLE 4: Notable chemicals intentionally used in hydraulic fracturing fluids. Information is based on reports by Waxman et al.[51] and Colborn et al.[45] The most commonly used chemicals in Michigan are also reported following a search of FracFocus.org[35].

Chemicals found in highest number of products (Chemical Name; CAS #; # products); Ref: Waxman et al.[51]	**Chemicals found in highest number of products (Chemical Name; CAS #; # products); Ref: Colborn et al.[45]**	**Chemicals associated with the greatest number of possible health effects (Chemical Name; CAS #; # possible health effects); Ref: Colborn et al.[45]**	**Number of times chemical ingredient is reported to have been used in a Michigan well sites (n=12 sites reporting); Ref: fracfocus.org[35]**
Methanol; 67-56-1; 342 products; Isopropanol; 67-63-0; 274 products; Crystalline silica, quartz; 14808-60-7; 207 products; 2-Butoxyethanol; 111-76-2; 126 products; Ethylene glycol; 107-21-1; 119 products	Crystalline silica, quartz; 14808-60-7; 125 products; Methanol; 67-56-1; 74 products; Isopropanol; 67-63-0; 47 products; Petroleum distillate hydrotreated light; 64742-47-8; 26 products; 2-Butoxyethanol; 111-76-2; 22 products	12 possible health effects each: Naphthalene; 91-20-3 Ethanol; 64-17-5 Petroleum distillate naphtha; 8002-05-9; 12; 11 possible health effects: methanol; 2-Butoxyethanol; glutaraldehyde; fuel oil #2; formic acid; 2-ethylhexanol; ethylbenzene;	Ammonium persulfate; 7727-54-0; 14 times; Crystalline silica, quartz; 14808-60-7; 11 times; 2,2-dibromo-3-nitrilopropionamide; 10222-01-2; 10 times; Methanol; 67-56-1; 10 times; Ethylene glycol; 107-21-1; 9 times; Acetic acid; 64-19-7; 9 times; Hydrogen chloride; 7641-01-1; 9 times Potassium chloride; 7447-40-7; 8 times

greater use of water and chemical components. Of the 13 reporting sites in Michigan, 11 wells reported to have a single hydraulic fracturing event, 1 reported 2 events, and 1 reported 3 events. The average number of chemicals disclosed for these 13 Michigan wells was 25 chemicals per well (range: 13-55).

In addition to the data provided in Tables 3 and 4, below we provide further information on five intentional-use chemicals (methanol, isopropanol, ethylene glycol, 2-butoxy ethanol, hydrotreated light petroleum distillates) that are prevalent in a number of hydraulic fracturing products. For each chemical, we briefly describe their role in hydraulic fracturing, relevant exposure routes, toxicokinetics, target organs, and potential health effects. A summary of potential health effects is also offered (Table 5) for these five intentional-use chemicals and a few other selected hazards. In terms of susceptible populations, workers in close proximity are at highest risk of possible exposures. Exposures to these identified chemicals would likely be in the form of inhalation and/or dermal contact.

2.7.1 Methanol (CAS 67-56-1)

Methanol is a colorless, volatile, and flammable liquid. It is used in hydraulic fracturing fluid broadly as a stabilizing and/or winterizing agent, corrosion inhibitor, crosslinker, friction reducer, gelling agent, and surfactant[35]. Individuals may be exposed to methanol through inhalation, ingestion, or dermal routes. Methanol is water-soluble and can distribute rapidly to a variety of organs, with about 60% of an inhaled dose absorbed[52]. Methanol toxicity is generally attributed to the metabolism of methanol to formic acid, which can reach levels high enough to cause acidosis in methanol poisoning; targets of toxicity include the optic nerve, kidneys, and other organs with high oxygen demand such as the brain and the heart[53]. In occupational settings methanol exposure can be monitored by measuring formic acid in the urine of workers[35]; however, since formic acid is also an ingredient in hydraulic fracturing fluid, and since other compounds used in hydraulic fracturing fluid (methyl ethers, esters, and amides) can also be metabolized into formic acid[53], this is likely not an adequate measure of methanol exposure in hydraulic fracturing workers. Other exposure monitoring methods should be sought.

2.7.2 Ethylene Glycol (CAS 107-21-1)

Ethylene glycol is an organic chemical that is odorless, colorless, and sweet-tasting. It is used in hydraulic fracturing fluid as a product stabilizer and/or winterizing agent, crosslinker, friction reducer, gelling agent, and non-emulsifier[35]. Ethylene glycol can be ingested, inhaled, or dermally absorbed, and workers are likely to be exposed by dermal or ocular routes. It is an ocular, but not a dermal, irritant[54]. Within the body, the chemical can be rapidly distributed[54,55]. Ethylene glycol may have cardiovascular, neurological, and renal effects[56]. Ethylene glycol exerts health effects primarily by two metabolites, glycolate and oxalate[54]; both metabolites contribute to renal effects[57].

TABLE 5: Summary of potential health effects for a number of physiological systems by notable chemicals. No information was found concerning endocrine, immunologic, or musculoskeletal effects. Data was summarized by reviewing ATSDR Toxicological Profiles and, when Toxicological Profiles were absent, MSDS sheets. Based on ATSDR Toxicological Profiles and The Globally Harmonized System of Classification and Labeling of Chemicals (GHS; a system for harmonizing various rating systems for chemical hazards) provided in MSDS for each chemical, the amount and quality of evidence for effects of notable chemicals on various physiological systems was assessed, with X = less evidence and lower quality, XX = intermediate amount and quality of evidence, and XXX = more evidence and better quality. These classifications were assigned by the authors based on their judgments.

Chemical Name	CAS	Carcinogen	Cardiovascular	Dermal	Developmental	Ecotoxicity	Gastro-intestinal	Hemato-logical
Methanol	67-56-1	X	XXX	XXX		XX		
Isopropanol	67-63-0	XX	XXX	XXX		XX	XXX	
Ethylene Glycol	107-21-1		XXX		XXX			
2-Butoxyethanol	111-76-2	XX	XX	XXX	XX	XX		XXX
Hydrotreated Light Petroleum DIstillate	64742-47-8	XXX		XXX				
Hydrogen Sulfide	7783-06-4			XXX				XXX
Silica	112945-52-5	XX		XXX				
Diesel	***	XXX	XXX	XXX				

Chemical Name	CAS	Hepatic	Neurological	Ocular	Renal	Reproductive	Respiratory	Irritant/ Corrosive
Methanol	67-56-1	XXX	XXX	XX	XX			XXX
Isopropanol	67-63-0	XXX	XXX	XXX	XXX			XXX
Ethylene Glycol	107-21-1	XXX	XXX	XXX	XXX	XX	XXX	XXX
2-Butoxyethanol	111-76-2	XXX	XXX	XXX	XXX	XX	XX	XXX
Hydrotreated Light Petroleum DIstillate	64742-47-8							XXX
Hydrogen Sulfide	7783-06-4			XXX	XXX	XXX	XXX	XXX
Silica	112945-52-5			XXX			XXX	
Diesel	***	XXX	XXX	XXX	XXX		XXX	XXX

2.7.3 2-Butoxyethanol (CAS 000111-76-2)

2-Butoxyethanol (also called ethylene glycol monobutyl ether) is an organic solvent that is colorless with a sweet odor. It is used in hydraulic fracturing fluid as a product stabilizer, given its surfactant properties[35]. 2-Butoxyethanol can be ingested, inhaled, or dermally absorbed, and within the body it is rapidly distributed[58]. Dermal absorption is highest when the chemical is present in an aqueous solutions (as would be encountered in fracturing fluids), and absorption can be enhanced with greater temperature and humidity[58]. Within the body, 2-butoxyethanol is metabolized to butoxyacetic acid (and other alkoxyacetic acids) by alcohol dehydrogenase[58]. Ethylene glycol may also result from the metabolism of 2-butoxyethanol. Case reports of accidental or intentional ingestion have reported hematuria, metabolic acidosis, pulmonary symptoms, and/or anemia, with patient recovery in each case[58]. The central nervous system is a target for 2-butoxyethanol, though this appears to manifest primarily as respiratory depression only at particularly high doses[59]. Exposures in humans have been associated with nose, throat, and eye irritation, headaches, and reports of a metallic taste in the mouth[58].

2.7.4 Isopropanol (CAS 67-63-0)

Isopropanol or isopropyl alcohol is a colorless and flammable liquid that has a strong odor. It is used in hydraulic fracturing fluid as a product stabilizer and/or winterizer, corrosion inhibitor, non-emulsifier, and surfactant[35]. Isopropanol can be ingested, inhaled, or dermally absorbed. Isopropanol may vaporize from solution thus indicating a possible inhalation source directly from hydraulic fracturing fluids or produced water. The main metabolite of isopropanol is acetone, which can be excreted rapidly in urine and expired air[60]. Based on its MSDS, Isopropanol can be a skin or eye irritant, and the target organs of toxicity include nerves, kidney, cardiovascular system, gastrointestinal tract, and liver[61].

2.7.5 Hydrotreated Light Petroleum Distillates (CAS 64742-47-8)

Hydrotreated light petroleum distillates (HLPD) are used in hydraulic fracturing fluid as a carrier fluid for borate or zirconate crosslinkers, polyacrylamide friction reducers, and guar gum in liquid gels[35]. HLPD are defined as a mixture of hydrocarbons, primarily C9-C15, and their composition may vary greatly depending on the exact source and production method[62], thus posing difficulties for assessment of health. HLPD can be ingested, inhaled, or dermally absorbed. Inhalation absorption is greater during exercise, indicating possible higher risk for workers, depending on their specific duties. It is recommended that any HLPD gas, fume, vapor, and/or spray not be inhaled. HLPD are an eye and skin irritant, and are potentially fatal if swallowed or enters airways. HLPD can also have a narcotic effect following a single exposure, with symptoms including drowsiness and dizziness; unconsciousness and death are possible with continued exposure. Some components of HLPD have also been implicated in neurotoxic effects such as balance, memory, coordination, fatigue, and reduced motivation at low concentrations for short times, which generally did not persist long after exposure. Such neurological effects may impact worker performance and contribute to injuries, should an exposure occur. Hematologic and kidney effects may also result from exposure. Some studies indicate a higher risk of certain cancers (prostate, central nervous system and lymphatic) among workers exposed to HLPD, but this higher risk has often been attributed to other components of complex mixtures to which workers are exposed. Rheumatoid arthritis has also been connected to HLPD by two studies, including one of women in Michigan and Ohio; however, exposures to other stressors existed and causal linkages were difficult to make[62]. Cable plant workers exposed to mist and vapor of petroleum distillates have developed pulmonary fibrosis, though again disentangling the effects of HLPD is difficult[63]. Long-term handling of HLPD may lead to dry and cracked skin. Susceptible populations may include those with skin disease, chronic respiratory disease, liver disease, or kidney disease. The presence of benzene in distillates may increase the magnitude of the hazard[64].

2.8 By-product Chemicals

In addition to chemicals used intentionally to facilitate drilling and well stimulation, there are a number of chemicals that may be released ‘unintentionally’. Machinery at the worksite may release chemicals (e.g., diesel exhaust and particulate matter) as part of normal functioning or from malfunctions. The extracted natural gas may contain chemicals such as hydrocarbons (e.g., methanol, benzene) and hydrogen sulfide. These chemicals in the natural gas can be removed following treatment with ethylene (or triethylene) glycol and heat, though the resulting “produced water” (i.e., water boiled off) and “condensate water” (i.e., volatile byproducts) would need to be managed accordingly. In addition, the water that returns to the well after fracturing has been completed (“flowback” water) is likely to be highly saline owing to the interaction of hydraulic fracturing fluids with naturally occurring minerals. This saline flowback water may also contain a number of toxic metal(loid)s, hydrocarbons, and naturally occurring radioactive substances. Another potential by-product are solid wastes that may be generated from drill cuttings, pit liners, sludge from recovered water, and other processes. Below we further describe some of the aforementioned chemicals.

We found one disputed report describing exposure of people to a number of chemicals in Michigan[34]. The 2003 survey from Manistee and Mason Counties alleges that a well leak of gas and fluids on October 28, 1998 from a natural gas operation not employing hydraulic fracturing resulted in a number of hospitalizations from exposure to methane, hydrogen sulfide, and other chemicals.

This report was not published in the scientific peer-reviewed literature, and the Michigan Department of Environmental Quality (Michigan DEQ) and Department of Community Health concluded that petroleum condensate vapors, not the gas leak, were likely the cause of the complaints and health effects[65]. Nevertheless, we provide this information here, as aspects may be relevant in future assessments and thus help decision makers and first responders anticipate and recognize potential issues.

2.8.1 Diesel

A variety of machinery at a hydraulic fracturing site may be diesel powered, including trucks, drilling rigs, and pumps. Given this prevalence, workers may be exposed to large quantities of diesel emissions on a regular basis. In general, there is a lack of information concerning the health effects of exposure to fuel oils, such as diesel, though inhalation of some fuel oils can lead to nausea, eye irritation, increased blood pressure, headache, light-headedness, loss of appetite, poor coordination, and difficulty concentrating[66]. In particular, long-term inhalation of diesel fuel vapors can damage kidneys and reduce blood clotting[66]. While there has been a great deal of research investigating the link between diesel exhaust exposure and cancer risk, it is inconclusive whether exposure leads to increased lung cancer in humans[67]. In addition to releasing diesel, this machinery may also emit other air pollutants (e.g., particulate matter) and contribute to noise pollution.

2.8.2 Methane

Exposure to methane, as a gas, usually occurs via inhalation. According to the U.S. Environmental Protection Agency's (EPA) Hydraulic Fracturing Study Plan[49], Encana Oil and Gas USA has released information that indicates that methane is either used in hydraulic fracturing fluid or is present in flowback/produced water. Aside from being a risk for fire and explosions, methane is an asphyxiant, particularly in confined spaces[68]. Methane may also act as an irritant of the respiratory tract, skin, and eyes[69]. Data on health effects from ingestion of methane are scarce, as this is not a common route of exposure, though it could occur since methane is a component in hydraulic fracturing fluids (likely flowback/produced water).

2.8.3 Hydrogen Sulfide

Hydrogen sulfide is a particularly dangerous chemical that can naturally occur in natural gas and thus it may be released during a hydraulic fracturing operation[70]. Hydrogen sulfide is a colorless gas that has the odor of rotten eggs; however smell cannot be relied upon to detect H2S as the gas can quickly impair an individual's sense of smell. It is denser than air, so can accumulate in low laying areas[20]. Hydrogen sulfide acts as an irritant and a chemical asphyxiant and is deadly at concentrations of 100 ppm. Exposure at lower concentrations can cause difficulty breathing and irritation of eyes, nose, and throat and can also result in long-term neurological effects including reduced motor function, poor memory and attention span, and headaches[71]. Hydrogen sulfide is also highly flammable and produces sulfur dioxide, another toxic gas, when it burns[70]. The OSHA Permissible Exposure Limit (PEL) for workers is 20 ppm and NIOSH recommends limiting hydrogen sulfide exposure to 10 ppm for a maximum of 10 minutes[71]. Monitoring of H2S is commonplace in hydraulic fracturing operations.

In Michigan, there have been reports of H2S releases from oil and gas industry operations in Manistee and Mason Counties occurring from 1980–2002[34]. Members of the surrounding communities reported that self-evacuations, medical treatment, and hospitalizations resulted from these H2S releases, but as earlier, we acknowledge that this report was not published in the scientific peer-reviewed literature.

3.0 THE SURROUNDING ENVIRONMENT

The environment that surrounds a hydraulic fracturing worksite may be the recipient of a number of hazards that originate from, or are caused by, the industry. In this section we discuss how hydraulic fracturing sites may impact ecosystem quality at the local and regional scales. Clean air and drinking water, as well as ecosystem services such as hunting and fishing, have direct linkages to human health and well-being[72].

3.1 Transportation

Many aspects of hydraulic fracturing operations lead to an increase in truck traffic in and around the site vicinity, including the use of trucks to transport drilling equipment, workers, and water to and from the site[73]. Road congestion was identified by shale gas industry experts as a high priority risk to the public and environment in a recent survey in which a variety of experts were asked to identify the most important risks related to hydraulic fracturing operations[74]. While truck traffic is likely to be elevated in and around a hydraulic fracturing site for the lifetime of the well, the majority of truck traffic occurs during the construction of the well pad, the hydraulic fracturing process, and the waste fluid and equipment removal process[73]. The number of heavy trucks needed during a hydraulic fracturing operation depends on the number of wells and well pads established at a site. For example, New York State Department of Environmental Conservation (NYSDEC)[73] estimates that 3950 one-way truck trips (with 1148 of those being heavy, fully loaded trucks) would be required for a newly created well and well pad (Table 6). This estimate is for a horizontal drilling hydraulic fracturing operation requiring ~5 million gallons of water, all of which would be transported to the site by truck.

The availability and location of water can affect amount of truck traffic. Sites that are able to pipe water to the site can reduce the number of heavy trucks needed from an estimated 500 trucks to 60[73]. This estimate may be more applicable to Michigan, where a number of facilities have reported obtaining water from onsite groundwater wells (e.g., State Excelsior 1-13HD1 from fracfocus.org[35]).

TABLE 6. Estimated number of one-way loaded trips for a single, horizontal well requiring a vertical and horizontal rig. Table modified from NYSDEC 2011[73], source: All Consulting 2010[75]. This information is specific for New York, but elements could be used to inform Michigan.

Well Pad Activity	Early Well Pad Development (all water transported by truck)	
	Heavy Truck	Light Truck
Drill pad construction	45	90
Rig mobilization	95	
Drilling fluids	45	140
Non-rig drilling equipment	45	
Drilling (rig crew, etc.)	50	140
Completion chemicals	20	
Completion equipment	5	
Hydraulic fracturing equipment (trucks and tanks)	175	326
Hydraulic fracturing water hauling	500	
Hydraulic fracturing sand	23	
Produced water disposal	100	
Final pad prep	45	50
Miscellaneous	-	85
Total one-way loaded trips per well	1,148	831

Truck traffic can have multiple impacts on the worksite and surrounding community, with noise, air pollution, and accidents of greatest concern[73,76]. Many roads, particularly those in rural areas, are not designed for the frequency and weight of heavy trucks, and thus road wear and erosion are likely to result[73]. Damage to roads in rural areas may put a strain on local and county finances, which may have fewer resources than more populated regions. For instance, the 2010 road budgets of 8 northern Michigan counties, where hydraulic fracturing is common, range from $3,099,902 (Montmorency) to $7,207,539 (Otsego)[77]. These were much lower than other urban and suburban Michigan counties such as Oakland ($93,817,982) and Washtenaw ($31,079,725).

Increased traffic can also lead to an increase in the risk of traffic accidents. In 2011, there were 284,049 traffic crashes in the state of Michigan, 834 of which were fatal crashes[78]. Only 17 of these fatal crashes occurred in the 8 northern Michigan counties mentioned above. A large increase in heavy truck traffic may thus greatly impact these rural areas. Traffic accidents involving vehicles transporting hydraulic fracturing fluid is a particular concern, because accidents involving these trucks may also lead to spills that could potentially contaminate surface water and soil in the area[49,73,76], though in our search we did not find any records of accidents in Michigan.

3.2 Air Pollution

Many aspects of the hydraulic fracturing process can result in air pollution emissions. While some air pollutants, such as diesel, methane, and hydrogen sulfide mentioned in earlier sections, may disproportionately affect hydraulic fracturing workers, these pollutants, as well as a wider variety of volatile organic compounds, criteria pollutants, and metals can also reduce air quality in the surrounding communities and ecosystems. The cumulative impacts of these are not clear.

Hydraulic fracturing operations are known to release many of the most common air pollutants, known as criteria pollutants, including nitrogen oxides (NOx), particulate matter (PM), carbon monoxide (CO), and sulfur dioxide (SO2), as well as volatile organic compounds (VOC) and other hydrocarbons[46,79]. Other contaminants can result from the release of certain pollutants, for instance VOC's and NOx emitted during hydraulic fracturing can combine with sunlight to create ozone (O3), and this has been estimated to occur in Wyoming. The cumulative impacts of multiple air pollutants being released from several facilities warrant attention.

The amount and types of emissions released is dependent on the stage of the hydraulic fracturing operation[46]. For each major stage in hydraulic fracturing, an estimated release of these pollutants is provided (Table 7). In addition, a table outlining key machinery and the types of air pollutants they may release is also provided (Table 8). Combustion engines emit major air pollutants, and are used during all stages of a hydraulic fracturing operation to run key machinery, such as compressors, pumps, trucks, and drilling rigs[46]. Air pollutants are also released during the well completion process, which vents or flares natural gas from the well, releasing methane and a variety of other air contaminants[80]. The EPA estimates that uncontrolled well completion processes for hydraulically fractured wells can vent approximately 23 tons of VOCs, which is 230 times more than conventional natural gas well completion[81]. A number of hydrocarbons may also be released into the air during a hydraulic fracturing operation. While hydrocarbons are often released during well completion, the exact source of measured hydrocarbons is often unknown, and they likely originate from multiple sources[79]. For methane, in Michigan this gas is to be captured in the tanks and flared. A recent survey asked a variety of experts to identify the most important environmental risks related to hydraulic fracturing operations, experts agreed that well venting during the well completion process was a high priority risk to the public and environment[74]. These experts also agreed that well flaring during the well completion process was not a priority risk. Flowback operations are also likely to be a key source of hydrocarbon emissions during the hydraulic fracturing process[79], though Michigan requires methane to be captured and flared at this stage.

The air pollutants released during hydraulic fracturing operations are known to have a range of adverse effects on human health. Inhalation is the dominant exposure route, though deposition into water and food may also occur. Respiratory and cardiovascular effects are best studied, though negative effects of air pollution on neurological, immune, reproductive, and developmental systems have also been documented. Cumulative effects of releases from multiple wells may affect regional air quality. Below we provide some key details for the relevant air pollutants.

3.2.1 Nitrogen Oxide (NOx)

Nitrogen oxide emissions come from motor vehicle exhaust and burning of natural gas and other fuel sources[82]. Low level NOx exposure can irritate the eyes, nose, and throat, as well as the lungs, which may result in coughing, shortness of breath, and fluid in the lungs. Inhalation of NOx at high levels can cause severe respiratory damage that can lead to reduced oxygenation and death. OSHA limits exposure of nitrogen oxide for workers to 25 ppm for an 8-hour day, for 40 hours per week[82]. The EPA standards for annual ambient nitrogen dioxide concentrations are set at 53 parts per billion (ppb) and 100 ppb averaged over one hour[83].

TABLE 7. Estimated annual emissions from various stages of hydraulic fracturing. Table assumes dry gas is present and the flowback gas is flared (units in tons per year). Table modified from NYSDEC, 2011[73].

	Drilling	Completion	Production	Flowback Gas	Total
PM	0.5	0.2	0.2	1.4	0.9
NOx	15.1	5.8	3.8	4.9	29.6
CO	8.3	3.2	9.2	24.5	45.2
VOC	0.8	0.2	2.4	0.7	4.1
SO2	0.02	0.01	0.07	0.0	0.1

TABLE 8. Summary of air pollutants and sources, which have been modeled for a hydraulic fracturing operation. Table modified from NYSDEC, 2011[73].

	SO_2	NO_2	PM10 & PM2.5	CO	Non-criteria combustion emissions	H2S and other gas constituents
Health Effect	Reduces lung function	Lung irritation and damage	Reduces lung function	Reduces blood oxygen		
Source						
Engines for drilling	X	X	X	X		
Compressors for drilling	X	X	X	X	X	
Engines for Hydraulic fracturing	X	X	X	X	X	
Line heaters	X	X	X	X	X	
Off-site compressors	X	X	X	X	X	
Flowback gas flaring	X	X	X	X	X	
Gas venting						X
Mud-gas separator						X
Glycol dehydrator					X	X

3.2.2 Particulate Matter (PM)

Particulate matter consists of very fine grain particles or liquid mixed within air. It is often made up of a variety of different components such as dust, smoke, and organic chemicals[84]. Inhalation of these particles, particularly very small particles, can cause them to become imbedded in lung tissues and negatively affect the lungs and heart. Studies have shown that inhalation of PM can cause heart attacks, reduce lung function, and exacerbate asthma. Children, the elderly, and people with heart or lung diseases are particularly susceptible to the negative health effects of PM[84]. The EPA standard for fine PM (PM2.5) is an annual average concentration of 12 micrograms per cubic meter (μg/m3).

3.2.3 Carbon Monoxide (CO)

Carbon monoxide can be produced when a natural gas well is flared during the completion process, as well as from combustion engines[46]. Inhalation of CO reduces oxygen delivery within the body, making people with low blood oxygen, caused by certain medical conditions, particularly vulnerable to CO effects[85]. Effects of CO inhalation include headache, nausea, vomiting, dizziness, blurred vision, confusion, chest pain, weakness, heart failure, difficulty breathing, seizures, and coma; exposure at high levels can be fatal[86].

3.2.4 Sulfur Dioxide (SO2)

Sulfur dioxide emissions are produced from the combustion of fossil fuels containing sulfur, such as gasoline and diesel[46]. Exposure to high levels of SO2 can be deadly, causing burns to the nose and throat and obstructing breathing[87]. Long-term exposure of low SO2 concentrations can cause changes in lung function and short-term exposure has been known to cause bronchoconstriction and increase symptoms of asthma[88]. The EPA standard for SO2 exposure is 1 hour at 75 ppb[88].

3.2.5 Volatile Organic Compounds (VOC) and Other Hydrocarbons

Volatile organic compounds are a group of organic compounds that are easily converted into gas form; burning gasoline and natural gas, and the dehydration of natural gas, can emit VOCs[46,89]. Little is known about exposure to low levels of VOCs, but exposure to high levels can cause long-term health problems related to brain, blood, and liver. Exposure to VOCs may increase cancer risks[89].

McKenzie et al.[79] sampled a variety of VOCs and other hydrocarbons including trimethylbenzenes, xylenes, aliphatic hydrocarbons, benzene, ethylbenzene, and toluene, during well development, production, and completion at a hydraulic fracturing operation in Garfield County, CO. Hydrocarbon emissions were detected with greater frequency and at higher concentrations in samples collected specifically during well completion activities than in samples collected in the general area of the well. McKenzie et al.[79] used the hydrocarbon levels found in the collected samples to determine chronic and subchronic non-cancer risk and cancer risk for residents living > ½ mile and < ½ mile from the well site. Residents living < ½ mile from the well had greater risk for chronic and subchronic non-cancer risk and cancer risk than residents living > ½ mile from the well. Chronic non-cancer risks were attributed to neurological effects, while subchronic non-cancer risks included neurological, respiratory, hematologic, and developmental effects. Benzene and ethylbenzene emissions were determined to be the greatest contributors for cancer risk.

Colborn et al.[90] also collected air samples around a hydraulic fracturing operation in Garfield County, CO. Samples were analyzed for VOCs, as well as polycyclic aromatic hydrocarbons (PAHs) and carbonyls. VOCs detected in 100% of collected samples included methane, ethane, propane, and toluene. Those detected in the greatest mean concentrations included methane, methylene chloride, ethane, methanol, ethanol, acetone, and propane. The carbonyls formaldehyde and acetaldehyde were also found in all collected samples, with the greatest concentrations detected for crotonaldehyde and formaldehyde. The PAH found at the highest concentration was naphthalene, and it was also detected in every sample. While concentrations of these air pollutants were detected at levels lower than government limits such as the REL and PEL, the effects associated with chronic, low-level exposure to air pollutant mixtures is not well known.

To our knowledge, air samples have never been collected in the vicinity of hydraulic fracturing operations in Michigan for the purposes of determining air pollutant concentrations.

3.2.6 Greenhouse Gases (GHG)

Many of the air pollutants released during a hydraulic fracturing operation are greenhouses gases (GHG). Notable ones include methane, carbon dioxide, and nitrous oxide. Jiang et al.[9] used emissions of these 3 gases to estimate the lifetime GHG production of a typical Marcellus Shale well. They included emissions from numerous GHG producing sources including trucking water and equipment, running drilling and fracturing equipment, methane leaks, emissions associated with gas production, processing, transmission, distribution, as well as natural gas combustion. In doing so, they estimated that a well produces approximately 5500 tons of carbon dioxide equivalent emissions. This estimate represents a 3% increase in lifetime GHG emissions for a hydraulically fractured natural gas well compared to a conventional natural gas well. Stephenson et al.[91] calculated a similar number, and estimated that hydraulic fracturing operations produce approximately 1.8 – 2.4% more GHG emissions than conventional natural gas wells. However, Howarth et al.[92] determined methane emissions from hydraulically fractured wells to be 30% greater than those from conventional natural gas wells, largely from methane emissions during the flowback and drill out processes. While there is uncertainty in the amount of GHG produced by hydraulically fractured natural gas wells, Weber and Clavin[93] examined 6 studies, including Jiang et al.[9], Stephenson et al.[91], and Howarth et al.[92], and could not determine whether hydraulically fractured or conventional wells produced a larger carbon footprint. Hydraulic fracturing operations could significantly reduce their GHG emissions by capturing gases that would normally be flared or vented during the well completion process[9,91].

It is also important to consider the amount of GHG emitted during both the hydraulic fracturing process and during combustion. While GHG are produced during the hydraulic fracturing process, combustion of natural gas during energy production has been estimated to be more efficient and produce less greenhouse gas emissions than other energy sources such as coal[9,91]. For the purpose of electricity production, Jiang et al.[9] estimated that hydraulically fractured natural gas produces 20-50% less GHG emissions during the lifetime of the well than coal. However, additional methane leaks during the natural gas production, transportation, and use may dramatically increase GHG emissions, particularly since methane is a more potent GHG than carbon dioxide produced from burning coal[94].

3.3 Water Quality

Of all public health issues, matters related to water quality and quantity appears to be of paramount concern. For example, a survey of 215 experts from NGO, government, and academia revealed that effects on surface water quality were a dominant concern, which is an interesting finding given that most in the public and regulatory world have expressed concern about ground water[95]. The potential impact on water quality and quantity from hydraulic fracturing in the State of Michigan is a focus of the paper by Burton et al. (2013) and Ellis et al. (2013) in this series.

Water is integral to hydraulic fracturing in a number of ways. For example, water is needed for key activities such as drilling, cooling and lubricating drill bits, and producing the hydraulic fracturing fluid. Wells situated in major shale plays, such as Barnett and Marcellus, may use an average ~5 million gallons of freshwater per well[96]. To put this into perspective, 5 million gallons of water is approximately the amount used by 50,000 people in one day. In Michigan, the amount of water needed to fracture a horizontal well may also be around ~5 million gallons[97]. For example, the State Pioneer 1-3HD1 well (Utica-Collingwood discovery well, Missaukee County) has used 6,720,000 gallons of water[98]. It should also be noted, that a typical shallow, vertical well in the Antrim Shale requires ~40,000-100,000 gallons of water[97,98]. When compared to other users of water, such as agriculture, the amount used in hydraulic fracturing is much less[99] (see Ellis, 2013 in this series). Nonetheless, concern may exist when activities are conducted in drought-prone regions or when water tables and river flows subside. Removal of water for hydraulic fracturing is viewed from a region's hydrologic cycle. Given the current reported low water levels of the Great Lakes (record low levels for Lakes Michigan and Huron since record keeping began in 1918)[100] the extra water use from expanded hydraulic fracturing operations in Michigan may further alter hydrologic conditions and may increase resident concern about water issues.

Below Table 9 shows the wide range of reported water use for wells with disclosure data in Michigan (as of March 10, 2013). Notably, the 5 wells with the greatest disclosed water use (State Excelsior 1-25, 2-25, and 3-25; State Excelsior 1-13; State Garfield 1-25) all reside in Kalkaska County; the State Excelsior wells 1-25, 2-25, and 3-25 are particularly closely clustered. Kalkaska County thus may be a priority for examining water resource impacts from high-volume hydraulic fracturing.

The potential impacts of hydraulic fracturing on drinking water resources are being studied by the EPA under its "Plan to Study the Potential Impacts of Hydraulic Fracturing on Drinking Water Resources". This plan is focused on addressing possible impacts on drinking water sources related to water acquisition, chemical mixing, well injection, flowback and produced water, and wastewater treatment and disposal. As outlined in their December 2012 progress report[96], a number of reviews of existing data, computer simulations, laboratory and field studies, and toxicity assessments are currently underway. The outcome of this overall study is expected to significantly improve our understanding of the potential risks of hydraulic fracturing to drinking water resources. However, it appears that Michigan is not included in the EPA's plan; thus, even after the EPA completes their study, there may be substantial gaps in our understanding of the potential impacts of hydraulic fracturing on water resources in Michigan.

3.3.1 Source of Chemicals into Water

Chemicals may be released from various stages of a hydraulic fracturing operation into the surrounding ecosystem. Chemicals may enter the environment following ruptures or mishandling of impoundment tanks or equipment, operator errors, and accidents. The drill cuttings may contain naturally occurring radioactive materials (NORM), and if not handled properly these may be a source of contamination. About 90% of the hydraulic fracturing fluid is water[96], though a number of chemicals are added to hydraulic fracturing fluids (Table 3) to optimize its properties as discussed above.

TABLE 9. Total Water Volume (gallons) for wells with disclosure information in Michigan[35].

Well	Total Water Volume (gallons)
State Excelsior 3-25 HD1	21,112,194
State Excelsior 2-25 HD1	12,562,096
State Garfield 1-25 HD-1	12,539,639
State Excelsior 1-25 HD1	8,461,635
State Excelsior 1-13 HD1	5,860,777
State Richfield 1-34 HD	4,804,620
Wiley 1-18 HD	1,420,939
Cronk 1-24 HD1	705,390
State Wilmot 1-21	33,306
State Marion & Riverside 14-36	25,914
State Marion & Riverside 14-36	23,023
State Marion & Riverside 14-36	20,918
Clayton Unit 44-31	20,701
Riverside 32-24	17,805
Wineman Unit B2-9	16,263
Wineman Unit B2-9	14,460

About 1% of the hydraulic fracturing fluid is composed of various chemicals (~50,000 gallons for a typical well that uses 5 million gallons of hydraulic fracturing fluid). These intentional-use chemicals may represent a contaminant source during use or flowback. There are reports documenting underground migration of contaminants, particularly in cases of inadequate construction of well casings and cementing, and plugging of abandoned wells[101]. It is important to realize that not all the injected water is recovered, 30 to 90% (1.5 to 4.5 million gallons of the 5 million estimated) may remain underground[96]. Wilson and Schwank (2013) in this series report somewhat better recovery, with only 25%-75% remaining underground. In addition to intentional-use chemicals, the produced water may pick up, depending on local geochemistry, a variety of salts, toxic metals, hydrocarbons, and NORM. In Michigan flowback water cannot be sent to wastewater treatment plants or be stored in open impoundments, rather they must be stored in large steel tanks or injected deep into the ground licensed deep disposal wells[3]. Further, as discussed by Ellis (2013) in this series, production of natural gas and underground injection of CO2 or flowback/produced water can alter the pressure gradients that drive groundwater flow. Though the vertical distances involved are large, this could potentially lead to altered water supplies for nearby communities particularly in the case of improperly capped wells.

3.3.2 Fate of Water-borne Chemicals

Hydraulic fracturing activities may contaminate water resources, though it is not clear whether people could be exposed to contaminants since exposure assessments and biomarker studies are lacking in Michigan and elsewhere. A 2011 study from the Marcellus Shale (Pennsylvania) analyzed 48 water samples from private wells before and after hydraulic fracturing to determine if water quality was affected[102]. The analyses revealed no significant changes in a number of water contaminants, such as chloride, barium, strontium, and methane. Another 2011 study from the Marcellus Shale (Pennsylvania) and Utica Shale (New York) analyzed 60 drinking water samples from aquifers that overlie the formations affected and not affected by hydraulic fracturing[103]. The analyses revealed that methane could be detected in 51 of 60 (85% of all) drinking water wells in the study region but that concentrations tended to be higher in samples taken closer to the natural gas wells. The research was not able to pinpoint the source of methane. Though this methane may be of thermogenic or biogenic origin, its origin may not matter greatly if its presence in drinking water is indeed a result of processes associated with gas extraction. Gathering baseline data prior to establishment and fracturing of future gas wells in Michigan could help to clarify whether or not such a relationship exists. This study did not find any evidence of chemicals used in hydraulic fracturing fluid in the samples tested, based on geochemical and isotopic features of tested water. Another study analyzed flowback water from 24 locations in the Marcellus and Barnett Shales; from each location influent (day 0) water was collected along with flowback water at 1, 5, 14, and 90 days following the fracturing event[104]. The analysis revealed that a number of general water quality parameters such as alkalinity, total dissolved solids, total organic carbon, sodium, calcium, barium, and iron differed between the flowback water and the influent water. In general, the author indicates that the water quality parameter values measured are normally seen in waters from conventional oil and gas operations.

In addition to studies that have directly analyzed water samples for potential contaminants, other studies have queried State groundwater investigation reports and regulatory officials. In a study performed by the Ground Water Protection Council concerning Ohio and Texas, there was only one horizontal hydraulic fracturing well in Ohio (prior to 2008) and more than 16,000 wells were completed in Texas over a 16 year period (1993-2008)[105]. The review of investigative reports from both states did not find any cases of groundwater contamination from hydraulic fracturing. The authors of this report also met with officials from eight States (Arkansas, Colorado, Louisiana, North Dakota, Ohio, Oklahoma, Pennsylvania, and Texas) and determined that, based on state investigations, no report of groundwater contamination in these states was associated with hydraulic fracturing. Given the widespread lack of baseline data on groundwater contamination near hydraulic fracturing sites, there is still substantial uncertainty regarding contamination because even elevated levels of contaminants near hydraulically fractured wells cannot be attributed to hydraulic fracturing without baseline data for comparison.

3.4 Habitat and Wildlife Impacts

The construction, operation, and maintenance of a hydraulic fracturing site may affect the landscape in a number of ways. Such landscape effects can have consequences for wildlife and ecosystems, as well as public health when opportunities for recreation, natural areas, and cultural/spiritual practices are affected. According to the Michigan DEQ, hydraulic fracturing has not been responsible for environmental damage in the State of Michigan[3]. The impact of hydraulic fracturing on ecological health is covered in this series by Burton et al. (2013).

The development of a hydraulic fracturing site requires the manipulation of land (e.g., via clearing and excavating), development and maintenance of primary (e.g., fracking pad) and associated infrastructure (e.g., pipelines, storage tanks), and construction and maintenance of roads to access the site. These types of activities are known to cause habitat loss. For example, oil and gas wells in the Kenai National Wildlife Refuge (Alaska) have removed nearly 1,000 acres of habitat[106]. Habitat quality may also be affected. The erosion created from aforementioned activities, if carried into surface waters, can have a number of adverse effects on local aquatic resources. Development may also fragment habitats and reduce forest and agricultural land cover[107], which is known to affect biodiversity and ecosystem health. For example, concerns have been raised about the possible effects of oil and gas-related habitat fragmentation on avian feeding and nesting[106]. Due to edge effects, habitat fragmentation has greater effects on smaller segments of intact habitat as compared to larger ones; thus the rate of degradation of habitat due to fragmentation can be expected to increase as development proceeds.

The source of water for hydraulic fracturing activities may come from local surface waters, municipal sources, groundwater aquifers, or even via recycling of hydraulic fracturing wastewater[106]. In Michigan, for example, the State Excelsior 1-13 HD1 well has drawn water from an onsite groundwater well for use in hydraulic fracturing fluid; a number of other Michigan wells have also obtained water from onsite groundwater wells[35]. Increased groundwater utilization could stress local water supplies. Surface water is not allowed to be used for hydraulic fracturing in Michigan. Such withdrawals from surface may affect stream flow and water quality[108], and this may affect the heath of aquatic organisms (fish, invertebrates) and riparian vegetation, as well as recreational opportunities such as fishing and canoeing. It is also possible that extensive withdrawals could affect water availability for other uses.

A U.S. Government Accountability Office (GAO) study found that of the 575 National Wildlife Refuges (NWR) in the U.S., 105 refuges contain a total of 4,406 oil and gas wells. Though rigorous scientific studies are lacking, the information available reveals that construction-related activities as well as spills and accidents have had a detrimental effect on wildlife and habitat[106]. A number of chemicals used intentionally in hydraulic fracturing, such as organic hydrocarbons, as well as produced brine water are known to be toxic to wildlife. In Michigan, two NWRs have had oil and gas activities. Kirtland's Warbler National Wildlife Refuge, one of few small areas with suitable summer habitat for the endangered Kirtland's Warbler, has two active oil and gas wells, 15 inactive wells, and multiple pipelines; oil and gas exploration activities continue on the Refuge. Shiawassee NWR has 4 inactive wells. It is noted that the intensity of oil and gas activity in Michigan NWRs is limited compared to other regions of the US, such as Louisiana.

3.5 Food and Animal Impacts

The possibility exists that hydraulic fracturing may affect companion and production animals. Bamberger and Oswald[39] interviewed animal owners near hydraulic fracturing sites in Colorado, Louisiana, New York, Ohio, Pennsylvania, and Texas, and report upon 24 cases of animals being affected. The interviewees reported witnessing adverse effects in a number of animals (e.g., deer, cows, fish, horses, dogs, chickens, song birds, and amphibian) in relation to hydraulic fracturing activities. In one case, an interviewee reported that hydraulic fracturing fluids were released onto a nearby cow pasture thus resulting in the death of 17 cows (necropsy report indicated most likely cause of death was respiratory failure). In another case, hydraulic fracturing fluid leaked onto a pasture in which goats exhibited reproductive impairments following exposure. A number of cases of exposure in farm production animals, mainly beef cattle and cows, were also documented. Exposures largely occurred via the spilling or leaking of hydraulic fracturing fluids or flowback/produced water into well water, ponds, and springs. In general, death was reported by farmers one to three days following exposures and reproductive impairment was the most commonly reported ailment. Effects were also documented in companion animals, including cats, dogs, horses, llamas, goats, and fish. Exposures in these animals likely arose due to ingestion of water from a contaminated source, and a range of neurological, reproductive, gastrointestinal, and dermatological effects were reported. Animals may serve as sentinels of human health risks, and in the report by Bamberger and Oswald[39] a number of health effects were also reported in several animal owners.

3.6 Earthquakes

The concept of anthropogenic earthquakes, in regard to hydraulic fracturing effects, has gained increased attention in recent years[109]. While the Michigan DEQ indicates that the state "does not have the conditions necessary for this to occur"[3], the University of Michigan CLOSEUP survey found that 2% of the Michigan residents questioned were concerned about the possibility of seismic activity. Small earthquakes, no matter the size, can be surprising to a community with no history of such events[110]. Concerns are not only regarding personal property damage, but also public infrastructure such as water and sewer lines[38].

To date, there is a lack of supportive data identifying hydraulic fracturing as a direct cause of earthquakes[109]. However, in 2011 seismic activity was reported in relation to oil and gas drilling by both the National Research Council in Blackpool, England and the Oklahoma Geological Survey. In addition, there is evidence of earthquakes in Ohio in relation to sub-surface fluid injection[111], the sole disposal method in Michigan according to Ellis (2013) in this report.

4.0 THE COMMUNITY ENVRIONMENT

4.1 Public Perceptions

A technical report in this series by Hoffman and Wolske (2013) is focused on social and public perception of hydraulic fracturing in Michigan. Here, we briefly highlight the salient points, given that an individual's comprehension of health-related choices lies at the core of public health[112]. The Center for Local, State, and Urban Policy (CLOSUP) conducted a telephone survey of 415 Michigan residents[13] between October 21 and 25, 2012, and found that a majority of residents have heard about hydraulic fracturing (82% have heard 'a lot' or 'a little' of fracking). The general reaction to the term 'fracking' was positive for 31% of respondents, negative for 45%, and neutral for 17%. Fifty two percent of respondents believe natural gas drilling will provide more benefits to the State of Michigan as opposed to 24% who believed that it would cause more problems. In terms of 'general stance on fracking', more than 50% either 'strongly' (32%) or 'somewhat' (22%) supported the activity. These numbers are similar to what has been found nationally, with 50-60% of Americans believing that the benefits of hydraulic fracturing outweigh the risks. Via open-ended questions, Michigan respondents indicated the top three 'most important risks' of hydraulic fracturing to be: water contamination (18%), health issues (14%), and other (11%). One-quarter (25%) of the respondents were 'not sure' or 'didn't know'.

The results from this CLOSUP survey are instructive at the State-level though they may not necessarily reflect opinions in regions where gas development is actively being pursued or amongst other sub-populations. There have been a number of news articles from across Michigan documenting public concerns about hydraulic fracturing (Table 9). While this Table is not an extensive review nor is it scientifically compiled, it does highlight that Michigan residents have a range of concerns and beliefs. In addition, it is important to note that in the Michigan CLOSUP survey, while many respondents have formed strong opinions in favor and against the activity, there are also a number of individuals who remained neutral or uninformed. For example, 17% of respondents indicated to have 'never' heard the term 'fracking', and >50% are 'not too closely' (32%) or 'not at all' (20%) following the discussion in Michigan. It is thus imperative to ensure that public health messages are based on sound science and that misinformation (especially in today's hyper-connected world) is immediately addressed[113]. Moving ahead, there is a need in both Michigan and nationally for an open and constructive dialogue among stakeholders (e.g., public, industry, government, academics, NGOs) who have different perceptions of the risks and benefits posed by hydraulic fracturing. A recent survey that asked a variety of experts to identify the most important environmental risks related to hydraulic fracturing operations[74] is an important first step in this regard.

It is also important to conduct focused studies on individuals that reside amongst hydraulic fracturing development sites. For example, the work by Bamberger and Oswald[39] is limited because individuals self-selected to participate; however, it does highlight a variety of concerns raised by local residents. There is a rich literature documenting individuals who believe they have been exposed to industrial chemicals; these individuals often develop chronic stress with health outcomes including depression, lack of control of the environment, increased family quarrels, increased health worries, and increased intrusive and avoidant thoughts[114,115,116,117]. In such scenarios, helplessness and fear of the unknown are common complaints[118]. Children of parents who report chronic stress from the uncertainty of toxic exposures also tend to report increased stress[114]. Trust in both governmental agencies and scientific experts erode when communities perceive a failure to adequately respond to toxic contamination[118]. In relation to hydraulic fracturing, polls reveal that many respondents and other stakeholders have concerns about the potential for groundwater contamination, ecological degradation, traffic accidents, and reduced quality of life[13]. To our knowledge, in Michigan there has yet to be a poll conducted specifically on people living in close proximity to hydraulic fracturing sites.

4.2 Michigan Counties

An understanding of the potential impact of hydraulic fracturing on Michigan communities requires some knowledge of the Michigan counties where the activity is taking place. Based on our review of well locations, 8 counties were identified that housed a majority of Michigan's hydraulic fracturing activity (Table 11; Figure 4).

TABLE 10. Selected news articles from Michigan concerning public concerns over hydraulic fracturing. These are for illustrative purposes only.

Date	Outlet	Title & Lede Sentence	Source
Jan 16, 2013	Cheboygan Tribune	Frack flowback used on county roads. An environmental group says it has learned that frack flowback was spread on roads in Cheboygan County in 2012…	http://www.cheboygannews.com/article/20130116/NEWS/130119634
Jan 30, 2013	Crawford County Avalanche	Hydraulic fracturing well pad construction has some residents worried,	http://www.crawfordcountyavalanche.com/articles/2013/01/30/news/doc51094b883c50f634275933.txt
December 27, 2012	The Hastings Banner	Fracking top local story of 2012	http://hastingsbanner.com/fracking-top-local-story-of-p4557-84.htm
December 20, 2012	The Detroit News	Study predicts Michigan fracking boon - Job gains from gas extraction touted, but some warn of risks	http://www.detroitnews.com/article/20121220/BIZ/212200359
November 12, 2012	Crain's Detroit Business	Splitting the state - Hydraulic fracturing frees gas and oil; opponents say environmental cost too high	http://www.crainsdetroit.com/article/20121111/FREE/311119998/splitting-the-state
November 8, 2012	MLive	Environmentalists plan 'fractivisim' meeting in oppose oil and gas exploration in West Michigan	http://www.mlive.com/business/west-michigan/index.ssf/2012/11/environmentalists_plan_fractiv.html
October 25, 2012	The Grand Rapids	Group files suit to annul state auction of oil and gas leases	http://www.mlive.com/business/west-michigan/index.ssf/2012/10/group_files_lawsuit_to_invalid.html
Oct 24, 2012	Lansing City Pulse	Frack this – six arrested, five face felony charges at anti-fracking protest at Lansing Center	http://www.lansingcitypulse.com/lansing/article-8021-frack-this.html
October 12, 2012	MLive	State officials move oil and gas auction to larger venue to accommodate anti-fracking protesters	http://www.mlive.com/business/west-michigan/index.ssf/2012/10/state_officials_move_oil_and_g.html
September 16, 2012	Bay City Times	Controversy over ' fracking ' intensifies - Gas exploration ramping up in state	http://www.mlive.com/business/mid-michigan/index.ssf/2012/09/michigans_natural_gas_industry.html

TABLE 11. Demographics and pertinent statistics in Michigan Counties with hydraulic fracturing.

	State of Michigan	Alcona	Alpena	Antrim	Crawford	Kalkaska	Montmorency	Oscoda	Otsego
Population, 2011 estimate	9,876,187	10800	29386	23316	14014	17160	9653	8608	24078
% of state population (Jul 2009)	100	0.11	0.29	0.24	0.14	0.17	0.10	0.09	0.23
% population change (2000-2009)	+0.3	-5.4	-6.5	+3.1	-0.5	+1.9	-2.1	-7.5	+0.5
Mean Household Income, 2007-2011	$48,669	$35,490	$38,081	$42,440	$39,597	$39,130	$34,490	$32,838	$46,303
% Below poverty	15.70%	15.30%	17.10%	16.70%	17%	16.50%	18.60%	20.10%	12.50%
% Bachelors Degree or Higher	25.3%	12.80%	15.40%	23.40%	15%	10.40%	10.40%	9.70%	20%
Arrests in 2001		187	1029	271	329	924	110	424	840
Arrests in 2011		162	1071	401	695	564	166	367	937

Collectively, these counties account for 1.37% of Michigan's total population. As shown below, the majority of natural gas extraction in Michigan is occurring in lower socio-economic areas. Pro-fracking arguments will likely present this as positive, framing it as providing higher wage jobs in low socio-economic areas; depending on the location and duration of added jobs, this may or may not be valid (as discussed by Zullo and Zhang (2013) in this series). Anti-fracking arguments will likely present this as negative, such as by arguing that lower socio-economic areas will bear the burden of fracking's negative effects while other distant communities receive the benefit (a form of environmental injustice, see Section 4.3).

4.3 Environmental Justice

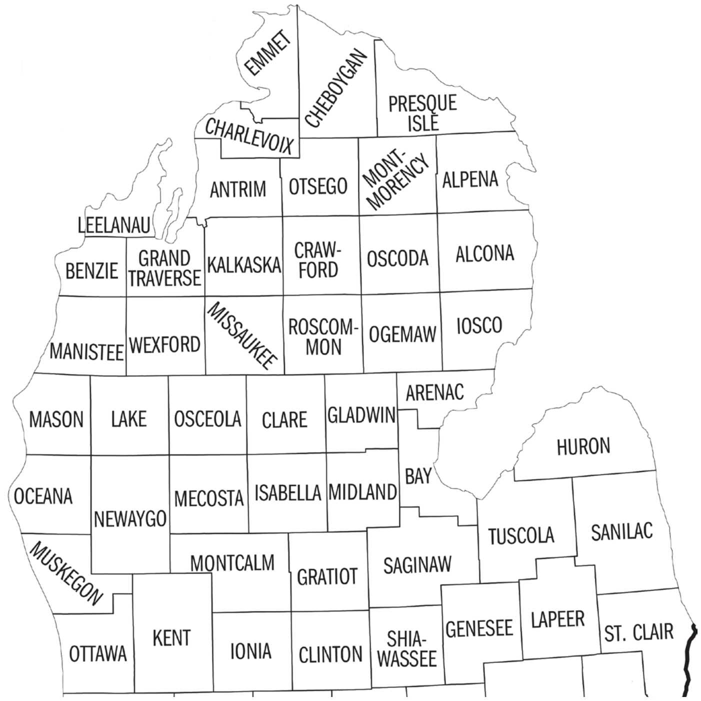
Environmental justice "is the fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income, with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies"[119]. Stakeholders involved in the EPA Water Study report have raised environmental justice concerns, and the possibility that hydraulic fracturing activities may disproportionately occur in or near susceptible communities. In the case of Michigan, it is not clear whether environmental justice is occurring, or is of concern. However, it is important to note that the mean household income is lower in each of the 8 counties identified earlier than the State-average, and the percent of individuals below poverty is slightly higher than the Michigan average for most Counties. This is of particular concern since Michigan ranks in the bottom half in the U.S. in terms of per capita income and other measures of socioeconomic success.

4.4 Boomtown Impact Model

A Boomtown Impact Model or social disruption model refers to the socio-cultural changes experienced by communities as a result of rapid population increase due to emergence of new industry[120,121,122,123]. Utilizing rich literature from the 1970s and 1980s, when rural regions in the United States underwent significant energy development, Jacquet illustrates this concept as it pertains to natural gas development and the hydraulic fracturing culture[17,123,124]. While quantitative data is limited due to the general lack of pre-boom baseline studies[121,125], the effects experienced by impacted communities provide various opportunities and challenges in relation to population, demographics, governance, geography, and local infrastructure.

From Table 11, there is no clear evidence of a population "boom" in the Michigan Counties in which hydraulic fracturing is occurring. Nonetheless, there are a number of potential public health concerns at the community-level that need to be considered if development activities are to rapidly increase. These are highlighted in the real-world examples that follow in the sections below.

Figure 4. Map detailing Michigan Counties identified in Table 11.



4.4.1 Health and Social Services

In the Boomtown Impact Model, the majority of recorded negative impacts are in regard to community distress and demands on social services[28]. This is because a population influx can extend community services beyond their capability. For the residents who already experience barriers to access, whether geographical, financial, or physical, a population influx may further hinder access[126]. Fire protection, traffic control, road maintenance, parking, zoning, and subdivision regulations are examples of factors that may be affected[127]. If workers are accompanied by their families, local school enrollment and recreational opportunities may be affected[28]. Enumerating community health can be difficult though factors such as mental health, crime, substance abuse, and sexually transmitted infection (STI) rates can be more easily identified[28]. First coined by Dr. Eldean Kohrs in 1974, Albrecht[120] describes the above lack of social services and public resources as the "Gillette Syndrome" in reference to the excessive social problems experienced in Gillette, Wyoming during an energy development boom. In this community, family tensions, emotional breakdowns, divorce, and increased alcoholism were all associated with the rapid community growth.

Demands on medical services have often been reported in industrial boomtowns. If new workers are insured these heightened demands can actually help to support the healthcare system. However, if workers are uninsured, additional strain on limited resources and effects on healthcare quality could occur. Statistics on health insurance coverage rates for natural gas workers are unavailable[28]. New skills are also needed for emergency responders to most effectively respond and adequately assist on the drilling site[120]. For example, Jacquet[123] compared the number of monthly Emergency Medical Service calls in Sublette County (Wyoming) with the number of drilling rigs over the period of 2001 and 2007, and found a highly significant correlation ($p<0.001$; $r2 = 0.695$). Due to long working hours and possible geographic isolation, on-site workers may become apathetic towards their own health status, especially when symptoms are not present. In addition, the lack of accessible physical and mental health resources poses barriers[128]. Workers may also have a tendency to binge drink and use drugs to relieve stress and help with cope with irregular and long work hours[128]. These can also be direct factors in the increase in STIs amongst workers. STI's tend to be perceived as highly stigmatized in these communities due to potential hyper-masculinity, sexism, and general apathy especially when no symptoms are present. For example, chlamydia rates amongst youth 15-24 years old working and/or living near the oil and gas industry "boom" area of British Columbia (Canada) were 22% higher than the provincial average, which could be a low estimate due to a lack of testing and sexual health resources[128].

Rapid growing communities have documented disproportionate rises in crime. A classic sociological viewpoint of this phenomenon is that the criminal activity is likely fueled by the growing transient workforce[120]. Freundenberg[129] questions this assumption and categorizes law enforcement records as subjective data, vulnerable to agency manipulation and variations in record keeping practices. It is also noted that crime rates are based on census population numbers and may not include the temporary workers in non-traditional living arrangements. However, Jacquet argues that proven causality is challenging but that reported criminal activity does have a positive association with increasing population[123]. For example, Jacquet's assessment of Sublette County (Wyoming) shows that between 1995 and 2004 the population grew by 21% and during that same time there was a 270% increase in the number of arrests.

4.4.2 Local Socio-Economics

Most studies have focused on macro-economic issues surrounding hydraulic fracturing. More data is needed which focuses on the community- and individual-level. At the community-level, inflationary issues, such as increase in rent, and property and employment pressures, are common[33,123]. This can be pared with higher taxes for long-term residents, in order to accommodate the heightened need for social services and industrial tax-break incentives[17,120]. Further, non-local workers will pay income taxes in their home community versus the community in which the wells are located[18].

Economic benefits may also be realized at the community and individual levels. Land lease payments and natural gas production royalties are one way in which local residents may earn income. In a case study done in Bradford County, Pennsylvania, where there are high levels of established Marcellus Shale development, leasing rates were reported anywhere from $5 to $5,000 per acre. The state minimum for royalties is 12.5 percent, with some residents receiving up to 20 percent[12]. As mineral rights ownership in Pennsylvania remain private, it is difficult to conclude whether or not residents who are directly affected by the industry are being adequately compensated. Even for local residents who are being compensated, these royalties generally only span a few years[18].

4.4.3 The "Bust"

As the development phases of hydraulic fracturing come to an end, communities begin to experience the "bust" portion of a "boom and bust" model. This period is characterized as a downturn in economic growth and reduction in employment. In order to mitigate the effects, it is thought that if other non-gas industry related investors become attracted to the area during the boom period, economic status could remain consistent. However, this has shown to be relatively difficult from a planning standpoint[123].

Effects experienced by the impacted communities provide various opportunities and challenges in relation to population, demographics, governance, geography, and local infrastructure. Typically, larger communities are better able to absorb the rapid development and population influx due to previously established infrastructure. Large transformations within a less populated community have greater potential for social disruption.

Brown et al.[125] proposed to add to the "boom-bust" model a period of "recovery", thus resulting in a "boom-bust-recovery" model. Via longitudinal studies, Brown et al.[121,125], found that long-term residents of the developed region typically experience increased community satisfaction during the post-boom years. They suggest older residences have a greater commitment and attachment to the area and have seen it through multiple transitions, therefore are less likely to be dissatisfied. Hunter et al.[122] refer to this transition as post-boom rebound.

5.0 CHALLENGES AND OPPORTUNITIES

5.1 Lack of Michigan Data

In Michigan approximately 12,000 wells have been hydraulically fractured, and the practice has been used on the vast majority of wells drilled in recent years (78%)[3]. High-volume hydraulic fracturing is less common, but the operation does exist in the State[4]. According to a Michigan DEQ factsheet, hydraulic fracturing has had no "consequence to the environment or public health"[3]. We found limited scientific evidence to discount nor support this statement, and this is problematic especially if development activities are to increase. Data are needed to establish baseline conditions, understand potential cumulative risks, assess trends over time and space, and to determine whether or not activities are proceeding in a safe manner.

The greatest challenge in assessing the potential public health risks of hydraulic fracturing in Michigan is the lack of State-specific data. While this challenge is specific to Michigan, it also applies to many other regions as concluded at the 2012 Institute of Medicine's Roundtable. Nonetheless, decisions need to be made and a number of potential hazards related to hydraulic fracturing exist; these have been reviewed in Sections 2, 3, and 4 of this report. In Michigan, however, there exists limited data on public health indicators (Table 2). While Michigan has had a long history of hydraulic fracturing, compared to other natural gas deposits, such as the Barnett and Marcellus Shales, the intensity and magnitude of contemporary hydraulic fracturing in Michigan is much less (i.e., most wells are low-volume, and high-volume hydraulic fracturing is not commonplace). A great opportunity exists for Michigan to learn lessons from other States, and put into place a mechanism by which baseline data may be properly collected, archived, and analyzed before high-volume hydraulic fracturing development intensifies. Without local and State-specific, objective, and peer-reviewed scientific evidence, it will be a challenge for risk assessors and decision makers to make sound judgments.

In terms of establishing a public health tracking system for Michigan's hydraulic fracturing industry, a number of models exist. In the Institute of Medicine's (IOM) report "The Future of Public's Health in the 21st Century", the U.S. Centers for Disease Control's (CDC) ten essential public health services were identified as part of a fundamental framework of activities that should be undertaken by all communities (Table 12). Many of these, such as monitoring community health status, and informing and empower people about health issues may be achieved via existing programs. Another example is the U.S. CDC's Environmental Public Health Tracking Program, which facilitates ongoing collection, integration, analysis, interpretation, and dissemination of data from environmental hazard monitoring and from human exposure and health effects surveillance[130]. Much of the discussion to date has focused on groundwater studies, though as realized via our review here, there exist a number of other important indicators that could be tracked in addition to water quality.

TABLE 12. The 10 essential public health services. From the U.S. CDC[131].

Monitor health status to identify and solve community health problems.
Diagnose and investigate health problems and health hazards in the community.
Inform, educate, and empower people about health issues.
Mobilize community partnerships and action to identify and solve health problems.
Develop policies and plans that support individual and community health efforts.
Enforce laws and regulations that protect health and ensure safety.
Link people to needed personal health services and assure the provision of health care when otherwise unavailable.
Assure competent public and personal health care workforce.
Evaluate effectiveness, accessibility, and quality of personal and population-based health services.
Research for new insights and innovative solutions to health problems.

5.2 Exposure Assessment and Epidemiological Causation

Much of this report may be viewed as a "Hazard Identification" exercise, which is the first step in human health risk assessment. As emphasized in the beginning of this report, the presence of a hazard does not necessarily mean that there will be a health risk to workers or community residents. Recall that a hazard is any biological, chemical, physical or psychosocial agent/condition that has the potential to cause harm. While a number of hazards clearly exist in hydraulic fracturing operations (=Hazard Identification), it next needs to be determined whether or not people are exposed to them (=Exposure Assessment). Such is the foundation of risk assessment (Figure 2). While hazards have been identified, few exposure assessments have been conducted in hydraulic fracturing sites, and even fewer have tried to account for their possible cumulative health impacts. Despite studies now measuring a number of chemicals and agents in air and water, to our knowledge research has not yet tied these hazards to any internal dose measurement via biomarkers (e.g., urine, blood, breath). To our knowledge, no such activity (even basic ones to assess air and water quality) has been published in Michigan, and this represents a challenge.

Another challenge in any human health study concerns epidemiological causation. Even if a hazard is identified at a hydraulic fracturing facility and people become exposed, linking it to an adverse health outcome (=Dose-Response Study) through an exposure-disease model will require carefully designed epidemiological studies that include, for example, a robust sample size, state-of-the art exposure assessments, temporal sampling to assess potential latent effects, and replication by others. Foundational elements described in Hill's criteria for causation should be followed, as would be expected in any rigorous epidemiological study. Ideally, these efforts would already be underway given the extent of existing hydraulic fracturing in the State of Michigan. One major criticism of risk assessments from other States concerns a lack of baseline data. While this criticism also applies to Michigan, compared to other States such as Pennsylvania and Texas, the magnitude and intensity of high-volume, horizontal drilling is much less in Michigan and thus an opportunity may still exist to initiate studies that may qualify as baseline.

There exist a myriad of hazards in the hydraulic fracturing industry, and not surprisingly many have advocated for the precautionary principle. Historically, action against harmful environmental and public health hazards has only occurred after the scientific community has proven its danger. In our report we were unable to find very many documented public health issues related to hydraulic fracturing (low-volume or high-volume) in Michigan, either because they have not been reported upon or they have not occurred. Nonetheless, before high-volume, horizontal drilling intensifies in Michigan, an opportunity should be seized to initiate basic yet important public health studies. The lack of these in other regions is leading to much criticism and debate, which Michigan has the chance to avoid.

5.3 Chemicals and Disclosures

There has been some disclosure of chemicals used in hydraulic fracturing fluids at sites in Michigan, perhaps representing a small sample of Michigan-specific data. The Michigan DEQ requires operators of high-volume hydraulically fractured wells to submit a Material Safety Data Sheet (MSDS)[i] for each chemical additive in the hydraulic fracturing fluid used, and the DEQ posts this information on its website. Based on the MSDSs for the 15 well sites posted on the website as of July 24, 2013[ii], an average of 18 chemical additives were used per well (range: 8-32)[132]. A subset of the high-volume hydraulically fractured well operators and other well operators have submitted information to FracFocus voluntarily. Via the FracFocus database, 12 Michigan well sites uploaded data as of January 29, 2013. From these, the average number of chemicals disclosed per well was 25 (range: 13-55).

This disclosure is, however, minimal with only a few facilities reporting upon a small number of drilling events out of more than 12,000 past and presently operating wells that have undergone hydraulic fracturing in the State. In the case of reported additives, the chemical identity of certain additives is withheld as a trade secret on the MSDSs. In addition, the information available on either website does not include data regarding the amount of chemicals used, even though operators of high-volume hydraulically fractured wells are required to report the total volume of each additive to the DEQ. Beyond the MSDSs and FracFocus database we are not aware of any published studies that report upon levels of chemicals in air and water near Michigan facilities. This lack of information represents a challenge. Considering that ~1% of the hydraulic fracturing fluid is composed of various chemicals (~50,000 gallons for a typical well that uses 5 million gallons of hydraulic fracturing fluid), chemicals are potentially being released into Michigan water resources.

Chemicals intentionally used in hydraulic fracturing serve a number of functions, but few of them have undergone rigorous toxicological testing. Moreover, the most prominent chemicals (Tables 4 and 5) are proven human health hazards. In addition, an outstanding feature in the toxicological sciences, which is of clear relevance to hydraulic fracturing, is the lack of understanding concerning toxicant-toxicant interactions (mixture effects), how these toxicants may change with varying temperatures and other industrial conditions, and how toxicants may interact with non-chemical stressors (e.g., built environment, socioeconomic status, food security) to influence health.

Given the aforementioned challenges, an opportunity exists for Michigan State officials and industry to adopt schemes to minimize potential adverse effects associated with the use of chemicals. For example, Encana[133] has a Responsible Products Program which "helps ensure that the hydraulic fracturing fluid products we use in our operations are as safe, effective, and as environmentally responsible as possible". This resulted in a risk-based product assessment and management program, and has led the company to stop using 2-butoxyethanol, benzene, and diesel in its hydraulic fracturing fluids. Chesapeake Energy, via the Green Frac[134] program they initiated in 2009, has a similar mission. Green Frac and other programs are also embracing green chemistry principles that seek to remove the most hazardous chemicals from operation and replace them with environmentally friendly alternatives.

5.4 Public Health Outreach and Education

Surveys indicate that the Michigan public is divided, where some residents support hydraulic fracturing and others do not, and residents also have some confusion regarding hydraulic fracturing[13]. An increase in public health education and outreach regarding hydraulic fracturing could aid Michigan residents. The 2012 CLOSUP survey of 415 Michigan residents revealed that a majority of respondents have heard about hydraulic fracturing and that most have a negative or neutral reaction to the term 'hydraulic fracturing'. Though, more than half the respondents believe natural gas drilling will provide more benefits to the State, and more than half

i The Michigan DEQ Guide to Environmental, Health, and Safety Regulations (2012) Appendix E provides a summary of what is included in an MSDS. Available: http://www.michigan.gov/deq/0,4561,7-135-3310_4148-15820--,00.html

ii Information added by report editor in collaboration with report author.

either 'strongly' or 'somewhat' support the activity. Many respondents also expressed uncertainty for a number of questions, which seems to be the case across many States, such as Pennsylvania[135]. Given the divide in public opinion responses, coupled with a range of media reports, anecdotes, and mis- or lack of information, a limited number of objective and peer-reviewed scientific studies, and a growing industry, there is a need to better communicate risks and benefits to all stakeholders, including the general public.

Providing inclusive community access to information and meaningful participation is a foundational principle in public health[136]. In order to address this issue, taskforce committees could be formed at a variety of levels given the varying opinions and diverse stakeholder groups[137]. At the community level, this taskforce could be composed of neighborhood residents, local government officials, public health professionals, businesses, industry representatives, and landowners. Such a taskforce would then be responsible for creating a fair and transparent forum and could also oversee baseline, local studies. To our knowledge, such taskforces do not exist in Michigan though could be achieved with limited resources.

5.5 Public Health Benefits and Tradeoffs

There exist no risk-free energy development schemes, and all activities (renewable and non-renewable) pose some degree of risk to public health. Therefore, any public health assessment of hydraulic fracturing in Michigan needs to be conducted with careful consideration of other energy sources, relative tradeoffs, and associated public health risks and benefits. It must also be realized that risks and benefits can vary from the local to regional/State, national and international levels.

The energy marketplace in the U.S. is shifting with the reliance on coal and hydroelectric diminishing and reliance on natural gas increasing (Figure 5). This is being driven by abundant and relatively cheap natural gas reserves, coupled with new rules governing power plants such as the Mercury and Air Toxics Standard (MATS). The opportunities associated with this shift include new jobs and increased economic activity, a more diverse and stable energy base, and decreased reliance upon foreign sources. In addition, utilizing natural gas instead of coal or oil may also yield improved air quality. For example, the deceased dependency upon coal (48% to 36% from 2008 to 2012) has been estimated to reduce carbon dioxide releases by 300 million tons or 13%. Release of other notable air pollutants has been estimated to be lower from natural gas operations when compared to oil and coal (Table 13). However, there still exists some debate concerning the release of methane, and thus contributions to greenhouse gas emissions[92,93,94]. The derivation of such numbers needs to be performed at the level of the State, nation, and world.

Figure 5. Proportion of energy arising from various sources. Coal-fired electricity generation is declining rapidly as the use of natural gas and renewable energy expands. Source: EIA, "Annual Energy Review", September 2012 and EIA "Electric Power Monthly," October 2012, cited in JISEA, November 2012.

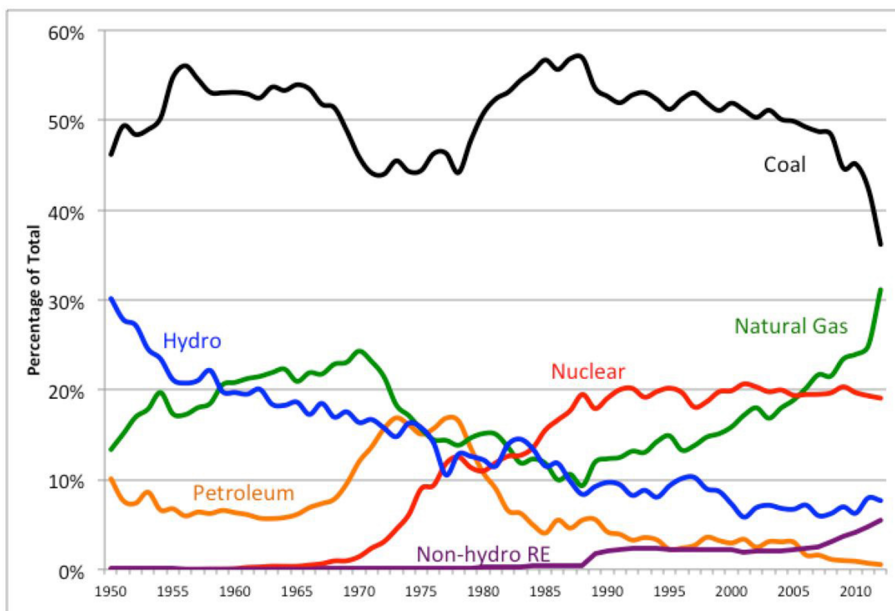


TABLE 13. Combustion emissions (pounds/billion BTU of energy input) from natural gas in relation to oil and coal. Adapted from DOE report.

	Natural Gas	Oil	Coal
Carbon Dioxide	117,000	164,000	208,000
Carbon Monoxide	40	33	208
Nitrogen Oxides	92	448	457
Sulfur Dioxide	0.6	1,122	2,591
Particulate Matter	7.0	84	2,744
Formaldehyde	0.750	0.220	0.221
Mercury	0.000	0.007	0.016

There seems to be some consensus in the public opinion that hydraulic fracturing may offer more 'benefits' than 'problems' (in Michigan, 52% indicating 'more benefits' versus 24% indicating 'more problems'[13]). Via an open-ended question on the 'primary potential benefit of fracking', 27% of respondents in Michigan indicated that it is a mechanism to attain energy independence and 15% said that it will reduce carbon emissions. Results from Pennsylvania were similar to Michigan.

TABLE 14. Potential public health trade-offs when shifting from coal and oil to natural gas as principle energy source.

Pros	Cons
• calculations suggest less air pollutants will be released; • may promote development of new generation of machinery and technologies; • terrestrial footprint of a horizontal hydraulic fracturing operation may be less than a conventional vertical oil & gas operation	• cheap natural gas may hinder development of potentially "greener" renewable energy technologies; • foreign energy suppliers may shift exports to countries less able to cope with increased development and pollution; • methane release and global warming potential remains debated

6.0 PROPOSED PRIORITIZED PATHWAYS FOR FUTURE WORK

6.1 Michigan-Specific Evidence

Based on Sections 5.1 and 5.2, empirical data is needed in Michigan concerning a number of public health indicators, such as air and water quality, exposure assessments in workers, and health of fish and wildlife. Such data is needed to help establish baseline measurements, make judgments against acceptable thresholds, and compare to other hydraulic fracturing regions. There are some important datasets available (e.g., well locations), and to broadly assess potential for risk these could be overlaid with datasets such as location of homes, agricultural fields, hospitals, and schools. The current report can be viewed as one that has identified a number of potential hazards.

6.2 Chemical Disclosures

Based on Section 5.3, there needs to be much greater understanding of what chemicals are being used in every well, with information related to volumes, amounts, disposal plans, etc. made available. Only a handful of wells have disclosed.

6.3 Public Opinion, Education, and Outreach

Based on Section 5.4, more public opinion surveys are needed, particularly local-scale surveys from affected communities. In addition, meetings engaging all stakeholders should be promoted and facilitated to gain a deeper understanding of varying perspectives. Trusted social scientists should be enlisted to carry out such activities, rather than those viewed to have biases.

6.4 Tradeoffs

Based on Section 5.5, all energy development schemes have inherent risk and thus a health economist should be enlisted to help enumerate risks-benefits of hydraulic fracturing in Michigan versus alternate energy sources, both in terms of health outcomes but also economic value.

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