A WHOLISTIC REVIEW OF HIGH VOLUME HYDRAULIC FRACTURING

AND ITS RELATED ENVIRONMENTAL, ECONOMIC AND SOCIAL CONSEQUENCES.

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I. ABSTRACT

High volume hydraulic fracturing of sedimentary shale deposits has recently led to the realization of several environmental, economic and social consequences. "Fracking", as the high volume hydraulic fracturing (HVHF) technique is commonly known, is rapidly generating discussions of these consequences in many areas of intellectual study, including: geology, sociology, geography, economics, engineering and law. Recent technological advances have spurred the rapid deployment of this method of fossil fuel recovery at such a rate as to preclude what many believe would be a prudent analysis of the effects fracking will have on other resources held in the public common. The rate at which fracking is growing is reflective both of the amount of energy resources able to be recovered by this method and the continued global demand for increased energy production. While the economic importance of fracking should not be underplayed, studies are beginning to catch up with the resource extraction's externalities and how these externalized costs are affecting third party social and environmental systems. This paper will review literature and scientific studies in an attempt to portray to the reader a general understanding of these externalities and will seek to weigh the total potential cost of hydraulic fracturing against its total potential gain.

II. INTRODUCTION

In order to develop a balanced and informed view of what high volume hydraulic fracturing can add and detract from society, it is important to first understand the science and technology behind the technique. This basic understanding of the construction and operation of a hydraulically fracked shale gas well will offer three key insights into the complete cost/benefit analysis of HVHF: 1) the large volumes of hydrocarbon resources available when HVHF is utilized as compared to conventional wells and the socioeconomic boons produced as a result, 2) the probability of contamination of environmental resources such as groundwater, surface water, air and soil; 3) pathways for exposure to hazardous materials and toxins involved in HVHF as well as other effects that degrade human quality of life. The cumulative effects of these three insights will serve to gage the overall benefit or detriment of HVHF as it relates to economic, environmental and social issues. The realization of an encompassing cost-benefit analysis will assist communities in either pursuing or avoiding the practice of this technology, as well as guiding law-makers in determining proper oversights and regulations. Although this paper does not offer such an all-encompassing cost-benefit analysis, it does offer insights as to the areas of focus in which further research is needed in order to develop such an analysis.

III. OBJECTIVES

This paper's objective is to enlighten those not overly familiar with the dilemma of HVHF of geologic shale formations in the US, specifically the disparities that exist between parties that absolutely oppose or support this method of energy production. Attention will be brought to arguments for both sides in addition to the most recent scientific findings available to seek to ameliorate the polarized viewpoints of both die-hards and special interests in both camps

IV. METHODOLOGY

The study area of this paper will consist of the contiguous (continental) United States (US) and will focus on the portions thereof which contain hydrocarbon-rich shale formations (plays) which are necessary in the drilling of unconventional shale wells. Special attention will be paid to the Bakken, Barnett, Eagle-Ford and Marcellus shale plays (see figure 1). Data for this review will consist of scientific research with an emphasis on peer-reviewed and accepted literature, including government studies and official documents. An introduction to HVHF technology and history will be followed by detailed analysis of potential risks and benefits to environmental and socio-economic systems.

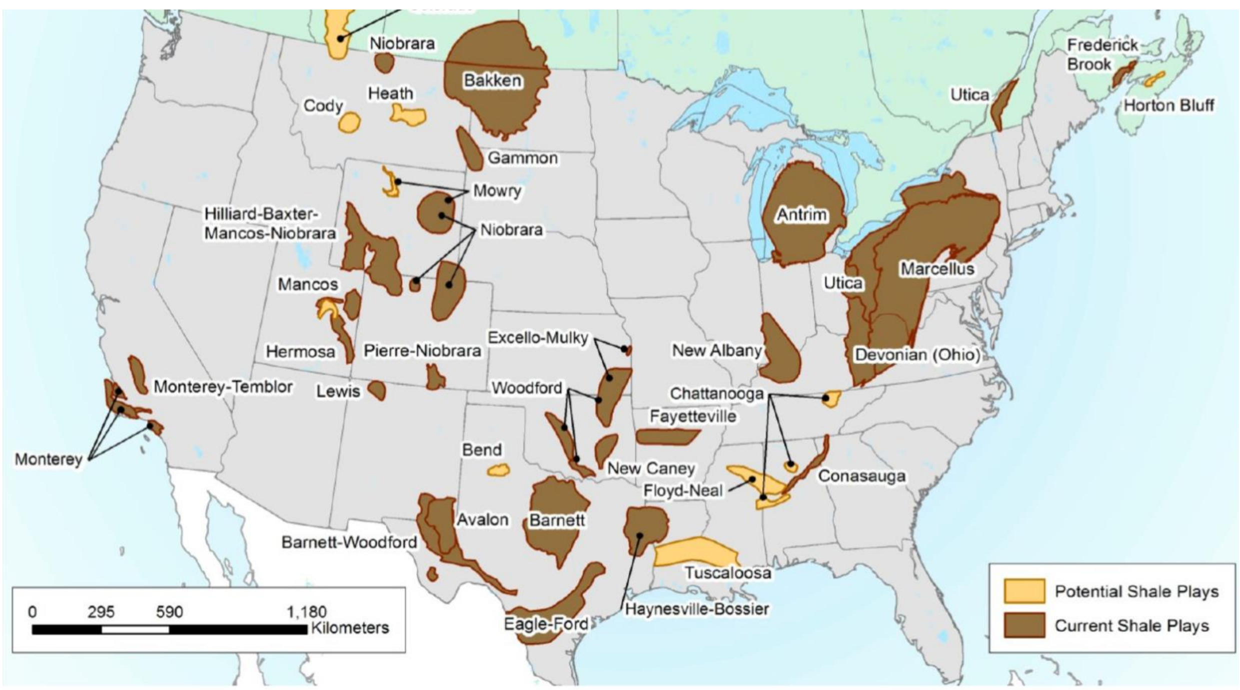

Figure 1: Unconventional Shale Oil and Gas Plays in the Contiguous US
Source: Vengosh, 2014

V. RESULTS FROM LITERATURE REVIEW

A. SCIENCE AND TECHNOLOGY OF HVHF

i. FORMATION OF ORGANIC-RICH SHALES

Shale is a sedimentary rock which is formed as clay minerals suspended in running water reach a large basin and settle out of the water to form sediment layers. Over geologic time these layers accumulate and become compressed by the overlaying layers, lithifying into shale rock. If the formation of the shale coincides with the deposition of organic materials and an anoxic condition exists, oxidative decomposition of the organic material will be abated and hydrocarbons will form in the pores between the mineral particles. Formations such as these are called source formations and over time the oil and gas that formed in the shale very slowly leak out of the formation through the shale matrix and through natural fractures in the shale to reservoir formations.

Reservoir formations generally have much higher porosities and are located at shallower depths than source formations, allowing for much easier extraction of the fossil fuels by what are commonly referred to as conventional wells. Many conditions must be met, however, in order for an ideal reservoir formation to form including the presence of a source formation, the maturity of the oil or gas in the formation, a reservoir formation with adequate porosity, a flow path from the source formation to the reservoir formation as well as an impermeable layer that traps the oil and gas in the reservoir layer (Soeder, 2012). It is due to the rarity of all of these conditions occurring in tandem that limits the actual number of conventional wells that may be drilled. Shale wells, on the other hand, do not require these conditions to be satisfied for a successful site, though the physical characteristics of the shale can affect the productivity of the shale play or formation. The difference in the availability and quantity of resource in conventional versus unconventional oil and gas wells is analogous to the picking of all the low-hanging fruit in an orchard (conventional wells) and the harder to obtain and much more abundant fruit near the middle and tops of the trees (unconventional wells).

ii. TECHNOLOGIES OF UNCONVENTIONAL SHALE WELLS

Although the first unconventional (shale) wells were dug nearly 200 years ago, large scale production of oil and gas from organic-rich shale plays was not economically feasible until the fruition of two necessary technologies: hydraulic fracturing and horizontal (or directional) drilling, (Fisher, 2010; Soeder, 2012). As discussed above, source formations have less porosity and permeability than do the reservoir formations used in conventional drilling; therefore, high-pressure fracking fluids (chemical composition discussed in section V.C.i) are utilized to forcefully break or "fracture" the shale. These fractures result in an increase in the number of flow paths for oil and gas to reach the well and eventually the surface.

Directional drilling is a process in which the well bores are deviated from the vertical to the horizontal. Due to the relatively shallow depth of the target source formation, dozens of vertical wells would have to be drilled to attain the same flow rates as a single horizontal well. This is because horizontal drilling allows for a greater contact area between the well and the shale source formation, see figure 2. These horizontal sections of well, which can exceed 1.5 Km in length (Engelder and Lash, 2008; and Soder, 2012) also allow for more hydraulic fractures in the formation, again increasing the amount of oil and gas which can be extracted from a single well.

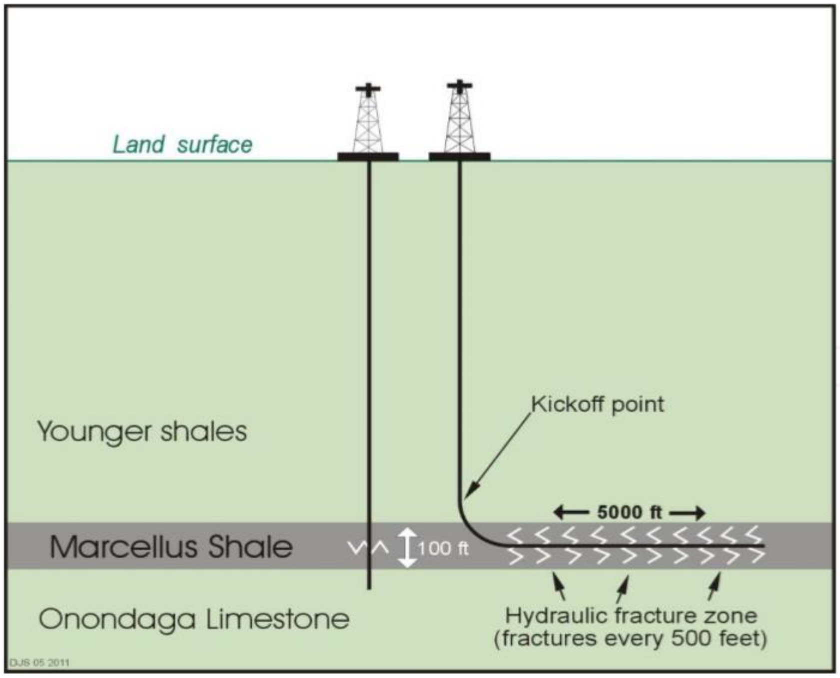

Figure 2: Effective Shale Production Area of Vertical vs. Horizontal Drilling
Source: Soeder, 2012

B. CONSTRUCTION OF A SHALE GAS WELL

In order to further understand the externalized effects of unconventional shale wells it is necessary to understand their general construction. This understanding of the physical components of the wells will enable the reader to have a general appreciation for the steps industry has taken to mitigate the risks involved in extracting resources from far beneath the earth's surface while realizing the many opportunities that still exist for something to go wrong during this process.

As shale wells are drilled they are lined with steel pipes known as casings to segregate the fossil fuels from groundwater and other subterranean resources (refer to figure 3). These casings vary in size from approximately 24” at the well “head” to about 5” at the end or “toe” of the well and telescope inside one-another until the desired well depth is reached (Soeder,2012). The conductor casing is the first to be installed and is designed to prevent the fragile surface soils from collapsing into the well. The conductor casing only extends approximately 50 feet, deep enough to reach the R-horizon of the soil profile (consolidated parent material or bedrock). Next a surface casing is installed from the surface of the well to 50-300 feet below the lowest layer of potable groundwater, generally 500-1000 feet but up to 1,500 feet below the surface in some cases (Fisher, 2010; Soeder, 2012). The purpose of the surface casing is to protect “good” groundwater that can be readily utilized for human consumption and to prevent aquifers from flooding the well. Depending on the depth of the well, a third casing known as the intermediate casing can be used, but can generally be interpreted as an extension of the surface casing with a smaller diameter and is not even necessary in some wells to reach the desired depths. Lastly, a production casing is set within the surface/intermediate casings from the head to the toe of the well. This casing will allow a flow path for the oil, gas and any flowback (hydraulic fracturing fluid returned to the surface) or produced water (naturally occurring subterranean water that is expelled from the well due to pressure differentials) from the shale play to the well surface.

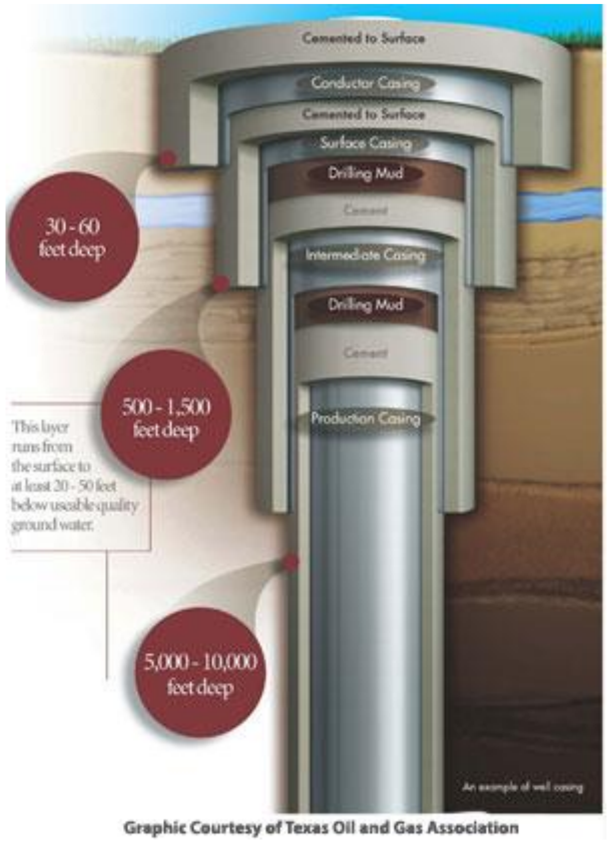

Figure 3: Diagram of HVHF Well with Casing Sections
Source: fracfocus.org, 2015, Texas Oil and Gas Association – https://fracfocus.org/hydraulic-fracturing-how-it-

Casings alone are not sufficient in preventing the mixing of groundwater with the fracking chemicals and the extracted resources. The casings are cemented into place to prevent the transmission of fluids along the annulus of the well (the space between the earth and the steel pipe) and to protect against borehole collapse. Without the cement, the casing may transmit fluids to the surface much the same way that a nail in a tire transmits tire pressure to atmosphere. The cement, if installed properly and allowed to set, will act as an adhesive that will block the flow of fluids (like plugging a tire hole with glue). The cement is either pumped down through the casing and back up through the annulus, a process known as “circulation”; or, in cases where this fails due to drilling through subterranean caverns or other lateral holes which absorb a significant amount of the cement; through a process known as "grouting." Grouting involves placing a steel collar or "basket" just above the lateral hole in the well wall and cementing the remaining space of the annulus. The grouting method of sealing a well annuls is much less preferred to the circulation method as the driving force behind grouting is merely gravitational force as compared to the higher pressure obtained by pumping the cement down through the casing and up through the annulus via the circulation method. The use of gravitational force as the main driving head for the grouting method may lead to cracks or voids in the final cementing of the well annulus. Also, having a section of the well exposed to a subterranean cavern may introduce a weakness in preventing casing erosion and subsequent contamination. Aside from the physical stability gained by cementing the casings in place, sealing the annulus with cement also acts as a barrier to dangerous gasses that could find their way to the surface of the well and lead to a blowout (as discussed in section V.C.ii.b).

Each section of the well must be drilled, cased and cemented independent of the other sections, that is to say that drilling for a sequential casing cannot (or should not) commence until the cement for the precious casing is cured. Curing is a process that varies with geological and meteorological conditions, but generally takes about 8 hours. Failure to allow the cement sufficient time to cure can lead to cracked or weakened cement and increases the probability of contamination or a blowout.

Once the well is drilled, the casings are in place and the cement is cured; a string of explosive charges or other chemical reagents which cause rapid oxidation are used to blast or melt holes in the production casing. These holes will then be used to transfer the pressurized fracking fluid into the shale play and fracture the rock formation. Once fracked, pressure on the fluid will be released and will allow the oil and gas to enter into the production casing and travel to the surface where it will be trucked or piped to market. As previously mentioned, the production casing lies inside the intermediate, surface and conductor casings providing added protection from groundwater contamination at the depths where groundwater exists. This does not preclude, however, the likelihood of groundwater contamination due to failures arising from design, construction, operation or other human errors.

C. PATHWAYS FOR ENVIRONMENTAL CONTAMINATION

As with any industrial process; byproducts, undesired responses and the process itself can have deleterious effects on the environment. Due to the rapid onset of HVHF, many of these effects are severely understudied and the long-term consequences to environmental systems can merely be speculated at this time. The biggest areas of concern with regard to environmental degradation due to HVHF are groundwater quality, surface water quality, air quality and, perhaps to a lesser extent, soil quality. Careful examination of these pollutant pathways, as well as the chemical makeup of possible pollutants, is necessary in order to preclude the most undesirable effects of HVHF on both human health and natural resources.

i. CHEMICAL ANALYSIS OF HYDRAULIC FRACTURING FLUID

Hydraulic fracturing fluid (HFF) is the liquid pumped down-hole at high pressure into an unconventional oil and gas well to cause the fracturing of the target shale play. Due to industry standards and government regulations the exact composition of HFF is deemed proprietary and is not disclosed; though the exact composition varies both between drilling companies and drilling sites. Some idea as to the chemical nature of HFF can be gleaned through self-reporting websites and through third-party analysis of flowback waters. Flowback is the industry term for HFF that was used to frack the shale well and has returned to the surface due to gas pressures forcing them up the well (up-hole).

Between 98-99% of HFF is water, either from previously fractured wells or fresh water. The remaining <1% consists of additives designed to increase the effectiveness of HFF and the resulting fractures. Typical additives of HFF are sand (used as a proppant to prevent fractures from closing), acids (used to dissolve minerals which may have precipitated in the fractures), viscosity increasing/decreasing agents, biocides (to keep bacteria from clogging fractures), corrosion and scale inhibitors and friction reducers (Gregory, Vidic, and Dzombak, 2011; Vengosh, 2014). Figure 4 lists common constituents of HFF, as well as their composition, purpose and an example of each.

Aside from the chemicals injected into the well in the form of HFF, the chemical composition of flowback waters can introduce additional potential pollutants as the HFF dissolves mineral formations deep beneath the surface of the earth. Heavy metals such as arsenic, selenium, barium, and strontium, as well as radioactive nuclides from naturally occuring radioactive materials (NORMs) such as radium have been found in flowback water (Lave and Lutz, 2014; Vengosh, 2014). Additionally, flowback waters may contain several types of hydrocarbons and generally have an elevated Total Dissolved Solid (TDS) concentration, which indicates the HFF is mixing with hypersaline groundwater formations. As many of the minerals and chemicals found in flowback water (either from HFF or mixing with natural formations) are toxic to biological systems, further study on the composition, fate and on likely pollution pathways is warranted.

Constituent	Composition (% by vol)	Example	Purpose
Water and sand	99.50	Sand suspension	"Proppant" sand grains hold microfractures open
Acid	0.123	Hydrochloric or muriatic acid	Dissolves minerals and initiates cracks in the rock
Friction reducer	0.088	Polyacrylamide or mineral oil	Minimizes friction between the fluid and the pipe
Surfactant	0.085	Isopropanol	Increases the viscosity of the fracture fluid
Salt	0.06	Potassium chloride	Creates a brine carrier fluid
Scale inhibitor	0.043	Ethylene glycol	Prevents scale deposits in pipes
pH-adjusting agent	0.011	Sodium or potassium carbonate	Maintains effectiveness of chemical additives
Iron control	0.004	Citric acid	Prevents precipitation of metal oxides
Corrosion inhibitor	0.002	n,n-dimethyl formamide	Prevents pipe corrosion
Biocide	0.001	Glutaraldehyde	Minimizes growth of bacteria that produce corrosive and toxic by-products

Figure 4: Volumetric Composition and Purposes of the Typical Constituents of Hydraulic Fracturing Fluid.
Table from Gregory et al. – compiled from 2004 EPA and 2009 API data.

ii. METHODS OF POSSIBLE GROUNDWATER CONTAMINATION

a. INITIAL DRILLING

During the initial drilling of a shale well, a bore hole is drilled from the surface to several hundred feet below the usable the usable water table. It is during this time, while the well is still uncased and the casing not sealed with cement, that mixing between drinking water aquifers and contaminated aquifers can freely mix. The relatively short time that the well is in this condition as well as the limited size of the well perforations, limits the contamination of the drinking water aquifer; although reduced availability of water to nearby drinking water wells may be observed (Myers, 2012).

b. METHANE CONTAMINATION

Following well completion; methods of contamination of fresh groundwater with methane, propane and ethane have been linked with failures of cement seals in the well annulus; improper seals between well casings; perforations in well casings; abandoned oil and gas wells with insufficient, failing or non-existent plugs and from natural or anthropogenic (i.e. from drilling or fracking) fractures in the strata underlying the aquifer. These methods of contamination allow for a flow path for the aforementioned aliphatic hydrocarbons to enter into fresh water aquifers and eventually to the surface. Build-up of these gasses can result in explosion hazards and are responsible for the cultural phenomenon of the flaming tap-water.

Industrially, a build-up of these gaseous hydrocarbons can lead to a well "blow-out" or the uncontrolled release of oil or gas. A blow-out was the cause of the BP Deepwater Horizon oil spill of 2010, which was reported to have had sub-standard cement seals in the well annulus which contributed to the disaster (Vengosh, 2014).

Many studies have been conducted on the possibility of shale wells (as well as conventional wells) leaking methane, ethane or propane into shallow ground-waters. Although these gasses naturally occur in aquifers, either through biogenesis or through natural dispersion from source formations, research involving hydrocarbon stable isotopes, molecular hydrocarbon ratios, and helium geochemistry have been recently employed in an attempted to describe the origins of gasses found in these aquifers. This research has led to the conclusion that in a subset of ground water wells sampled in northeastern PA (located < 1Km from a shale well) at least some of the gas found in groundwater is directly attributable to leaks from well casings or cement seals allowing flow paths from the target shale play or overlying intermediate strata to the groundwater (Vengosh, 2014). Additionally, measurements taken from the surface casing of a recently drilled shale well in Canada produced aliphatic hydrocarbons from intermediate strata indicating that the cement seals had already failed (Muehlenbachs, 2011).

Other research has shown that increased levels of methane and other gasses in groundwater were not the result of leaks from fracking wells, but were resultant of variations in groundwater topography. Molofsky, et al. found an inverse correlation between the elevations of well water sites and the wells' methane concentration, concluding that, "elevated methane concentrations in groundwater are a function of geologic features, rather than shale gas development." On the other hand, some research has found that while topography is a significant factor in the level of methane in water wells, it cannot adequately explain the variations in concentrations of methane with respect to distance from shale wells. Jackson et al. states, "This study examined natural gas composition of drinking water using concentration and isotope data for methane, ethane, propane, and 4He. Based on the spatial distribution of the hydrocarbons, isotopic signatures for the gases, wetness of the gases and observed differences in 4He:CH4 ratios, we propose that a subset of homeowners has drinking water contaminated by drilling operations, likely through poor well construction."

c. DISSOLVED SOILIDS CONTAMINATION

Due to their density, dissolved contaminants would appear at a much slower rate as compared to gaseous contaminants. Therefore it can merely be hypothesized as to how dissolved contaminants such as salts, heavy metals, etc. may find their way to fresh ground waters from hydraulically fracked directionally drilled shale gas wells. These contaminants may be in the form of naturally occurring brine waters or as displaced fracking fluids; however, either would potentially ruin the quality of an aquifer. Some research has suggested the contamination of water wells with pollutants similar to those produced during the fracking process, especially if methane has a pathway into the aquifer (Vengosh, 2014); however, methods of contamination of these water wells is little more than speculative at this time.

Another method of solids contamination of groundwater caused, at least in part, by hydraulic fracking of shale gas wells, is that of the precipitation of heavy metals through re-dox reactions caused by the oxidation of excess methane and the subsequent reduction of sulfites. These chemical reactions could potentially increase the chemical mobility of heavy/toxic metals such as iron, manganese and arsenic in groundwater. Although these metals may exist naturally in groundwater, the variations in groundwater chemistry potentially caused by contaminants in deeper strata may induce a toxification reaction in these heavy metals. Halogens in brines from fracking water or natural aquifers can also cause chemical bonds with methane to form toxic trihalomethanes (TCMs), although these reactions have not yet been documented as a result of shale wells. (Carter, et al., 2012 and Vengosh, et al., 2014).

Again, as with methane dispersion, another method of dissolved solids dispersal is through natural and anthropogenic fractures in the underlying strata of the ground water. Though this method is highly unlikely due to the depths of shale gas wells, the probability still exists, especially in regions with karst topography and highly naturally fractured regolith or where HF was allowed at shallower depths. As both the brines found in regions of organic-rich shale plays and fracking fluid both often contain salinities in excess of seawater (Gregory, Vidic, and Dzombak, 2011), the potential for damage to freshwater aquifers cannot be entirely ignored. On the other hand, many aquifers have recently undergone a notable salinization despite the absence of shale gas drilling, this may be in part to the increased demand on the fresh water aquifers and the subsequent pressure gradient between the fresh and saline water bearing strata.

iii. METHODS OF POSSIBLE SURFACE WATER CONTAMINATION

Surface water contamination is another potential source of pollution from gas shale wells. Surface water pollution can result from the improper treatment or handling of either flowback or produced water (water from natural formations expelled from the well after all flowback is presumed to be out). Collectively, flowback and produced water are sometimes referred to as fracking waste water or simply waste water. Approximately 10-40% of HFF returns to the surface as flowback and is either reused, disposed of in waste water injection wells (Class II wells) or treated and released to surface waters (Gregory, Vidic, Dzombak, 2011). The cost of this later form of disposal is very cost-prohibitive due to the volume of water utilized in HF, about 1-6 million gallons for one well (Lave and Lutz, 2014) and could cause undue burdens on municipal water treatment systems. Depending on the region the use of waste water injection wells may also be unavailable for flowback disposal due to an increased demand for injection sites occurring in tandem with increased unconventional well production. The reuse of flowback as HFF at another fracking site is growing in popularity among drilling companies, especially in areas where access to waste water injection wells is extremely limited, as this reduces disposal costs as well as decreases the amount of chemicals needed for sequential wells (Vengosh, et al., 2014 and Soeder, 2012).

No matter the method the drilling company choses to remove the flowback water after it has been expelled from the well, the water must either be held on site for future use/disposal or transported offsite. It is during these crucial times of onsite storage or transportation that the chance for a potential spill or discharge is greatest. Instances of flowback or produced water spills are not uncommon, as evidenced by the large number of citations issued to drilling companies for spills or leaks by state agencies (Entrekin, et al., 2011). Vengosh, et al., found that the occurrence of accidental spills or leaks doubles in areas of high density drilling (>0.5 well/km^2), such as in northeastern Pennsylvania.

Apart from the accidental spilling of flowback, improper or inadequate treatment and subsequent disposal have also been attributed to increased pollutants in surface waters. A 2013 study by Ferrar, et al., showed high levels of chemicals associated with hydraulic fracturing in the effluent of three waste water treatment plants in PA, with TDS thousands of times above stream background and elevated levels of toxic and radioactive metals in addition to BTEX compounds (benzene, toluene, ethylbenzene, and xylene). It is not surprising that the waste water treatment facilities have difficulties in “cleaning up” the flowback water as this was not their designed function. Additionally, the huge volumes of flowback that require treatment may prematurely wear out a waste water treatment system. Another common practice for some municipalities is to allow disposal of flowback via road-spraying to keep dust from becoming airborne or to prevent ice formation. This practice of disposal of flowback by spraying it on public roads is not only highly controversial at the municipal-level, but may be in violation of federal regulation regarding the proper disposal of flowback under the Clean Water Act (CWA) should the spray flow into surface waters of the US (more in section V.D).

Finally, the unauthorized disposal of untreated flowback into surface waters is undoubtedly illegal under the CWA; however, a government study concluded that this manner of disposal was likely responsible for the death and destruction caused to a benthic system in Kentucky (Papoulias and Velasco, 2013).

iv. AIR AND NOISE POLLUTION

Methane escape during the well construction process was an initial cause for concern during preliminary studies suggesting unconventional wells had the potential to release far more of the highly effective green-house gas than conventional wells (Howarth, Santoro and Ingraffea, 2011). This finding, however, is in contradiction to a more recent study which shows that the methane losses from unconventional wells are much lower than Howarth's original results (Jiang, et al., 2011). Further efforts to either detain (through better technology) or burn (a practice known as flaring) the methane expelled with the flowback may cause further reductions in methane leakage from unconventional wells to the atmosphere; resulting in fewer green-house emissions. The flaring process itself can add both light and noise pollution to the immediate area which may cause disturbances to both diurnal and nocturnal species in the immediate area, though these disturbances generally last a period of weeks.

A second form of air pollution associated with gas well sites comes in the form of volatile organic compounds (VOCs) including BTEX compounds. These chemicals are considered hazardous to humans at low concentrations (McKenzie et al., 2012). The EPA (under the authority of the Clean Air Act) is developing regulations to reduce well emission of BTEX compounds and other VOCs into the atmosphere sometime in 2015. Shale gas wells, using retro-fits and immerging technologies, may reduce VOC and BTEX emissions by gas wells by over 90% (EPA 2013, Lave and Lutz, 2014).

v. SOIL CONTAMINATION WITH HYDRAULIC FRACTURING FLUIDS

Few studies have been completed regarding the effects of HF waste water's effect on healthy productive soils. The constituents of waste water (discussed in section V.C.i) may be grounds for future research into soil contamination and possible methods of remediation, especially in regions where the storage, transport or disposal of waste water make accidental spills or leaks more probable. Perhaps the largest contaminant of concern regarding the addition of HF waste water onto healthy soils would be the large amounts of total dissolved solids (TDS) in the waste water. TDS concentrations can reach several times that of seawater (upwards of 150,000 mg/L) though these values vary significantly with geography and geology (Vengosh et al., 2014 and Gregory, Vidic and Dzombak, 2011). One study, conducted in WV, observed the collapse of a forest ecosystem after the experimental release of over 300,000 L of HFF spread over an area of 0.2 hectare (nearly ½ an acre) (Adams, 2011). During this study, the deterioration and death of understory plants were noticed almost immediately and trees began dying days later, with over 50 % of the trees in the study area dead within two years of the application of the waste water (Adams, 2011; Vengosh et al.,2014). While the application of such a large volume of HF waste water, 15 cm in average depth over a period of three days (Adams, 2011), is beyond the scope of minor spills and leaks; this experimental application nevertheless showed a plausible waste water exposure rate for deciduous forests in shale oil and gas regions and the resulting damage to forest flora.

vi. ADDITIONAL ENVIRONMENTAL CONCERNS

a. SEISMIC ACTIVITY

There is much debate as to the likelihood/extent to which the underground injection of fracking wastewater is causing seismic activity in regions containing UIC wells. Although UIC wells have been utilized for decades for the disposal of conventional gas well waste water; the rapid growth of unconventional drilling, combined with the increased volumes of water used in this process and the geographical change in demand for Class II injection wells have generated some concern over probable seismic consequences (Lave and Lutz, 2014). Recent studies are using seismic data in Oklahoma to preclude the worst possible effects of UIC wells in the region from triggering seismic events by determining placement of UIC wells away from active fault zones (Alt and Zoback, 2014). McNamara et al., however, notes a recent and dramatic 300-fold increase in magnitude 3 or greater earthquakes in north central Oklahoma as compared to previous decades with the potential for increased occurrences of higher magnitude earthquakes as the increased seismicity is occurring near active faults (2015).

b. HABITAT FRAGMENTAION

Due to the permeating presence of oil and gas within the clustered distribution of gas shale plays, the potential for a grid-like distribution of well sites is very real. This uniform distribution is not a phenomenon common to conventional gas wells, as the precursors to conventional reservoir formations (as discussed in V.A.i) are generally much smaller in geographical scope than when compared to an entire gas shale play. It is for this reason that the probability of habitat fragmentation and species endangerment is a very real issue with unconventional gas wells. Data is not yet available to quantify the amount of disturbance individual species may undergo due to habitat fragmentation from shale gas wells; however, some have pointed out that several species' habitats lie entirely within shale gas plays currently being developed using HF (Kiviat 2013). Additionally, due to the nature of shale gas wells, production rates at a well site tend to decrease drastically over the first 2-3 years (Zobak, Kitasei and Copithorne, 2010.) Therefore to maintain steady production, new wells must be continuously drilled or old wells must be re-fracked, increasing landscape disturbances, as well as exacerbating the problem of proper waste water disposal.

On the other hand, unconventional wells have a much longer “range” than do conventional wells and several boreholes can be drilled and fracked from a single site; these advantages may help to limit landscape disturbances and species fragmentation if biological planning is involved in the well site locating (Lave and Lutz, 2014).

c. USE OF WATER RESOURCES TO FRACTURE WELLS

There is a growing concern that, especially in regions prone to drought or with extended dry seasons, HVHF will put too high a burden on local water resources (Gregory, Vidic and Dzombak, 2011). This concern is not unfounded and can be especially serious in regions were agriculture and other industries have put a high stress on local water sources, including the freshwater aquifers being drilled through to make the unconventional shale well. While each unconventional well uses many times more water than a conventional gas well other facts must also be taken into consideration. As mentioned in the habitat fragmentation section above, the extended range of each shale well may reduce the number of wells needed to be drilled for a given amount of resources. Although fewer shale wells may need to be drilled, total water use may still be greater than that of conventional oil and gas wells as shale wells will periodically require re-fracking in order to maintain production of economically viable quantities of oil and gas. That being said, two other factors come into play to further complicate the issue of water use in HVHF, and they are that the practice of HF waste water recycling from well site to well site is continuing to grow (especially in regions with few Class II UIC wells for waste water disposal) and that the majority of water that is sent down-hole to frack the shale play generally remains in the formation and does not "blow back" to the surface (Vengosh et al., 2014). The water lost as reduced volumes of waste waters return to the surface of a well, while decreasing the environmental and economic costs of disposal of the waste water, may also increase the demand for freshwater from surface and ground systems. Additionally it is prudent to note that many other industries use vast amounts of freshwater daily, although these industries are likely not growing at the rate at which the HVHF industry currently is and are also likely not to be established in a region with water scarcities, as unconventional wells sometimes are.

D. ENVIORNMENTAL LAW REGARDING HVHF

The Safe Drinking Water Act (SDWA) is the premier law regarding the safety of drinking water aquifers in the US. This law regulates the injection of fluids into subterranean strata via the Underground Injection Control (UIC) Program. The 2005 Energy Policy Act amended the SDWA to specifically exempt the injection of fracking fluid, thereby giving industry permission to inject fracking fluids without regulatory oversight. It is important to highlight that flowback and produced waters (collectively, fracking waste waters) are not exempt from the SDWA and must be injected into regulated Class II UIC wells, if the drilling company choses this method of disposal.

Under the Resources Conservation and Recovery Act (RCRA), the EPA has the authority to classify fracking wastewater as a "hazardous material" given the nature of the constituents found in fracking waste waters. Since a 1988 regulatory decision by the EPA, waste waters from all onshore US oil and gas production has been classified as “non-hazardous” and is therefore not applicable to the stringent “cradle-to-grave” record-keeping guidelines of RCRA. Although many of the components of fracking waste water are considered as hazardous by the EPA, the concentrations of these hazardous materials are generally low (below the EPA thresholds for de-facto classification as a hazardous waste) and therefore the EPA would have to “list” fracking waste water specifically as a hazardous waste. Due to the tremendous volumes of fracking waste water generated in the US, listing fracking waste water as a hazardous material under RCRA may have a series of side effects that may cause an over-regulation of the waste water. The EPA determined that state and local agencies could effectively manages these wastes using programs that were already in place and that the costs of implementing control of fracking waste water as a hazardous material under RCRA would unnecessarily increase costs and administrative burdens (Gaba, 2014). One option between the two extremes of fracking waste water exemption from RCRA and EPA listing of waste water as a hazardous waste would be for the EPA to create custom exemptions for waste water from the hazardous waste regulations, eliminating any requirements that the agency deemed “unnecessary” while increasing the safe handling of fracking waste waters. In order for the EPA to grant fracking waste water “conditional exclusions” from the hazardous waste requirements of RCRA, the agency would first have to list the waste water as a hazardous waste (Gaba, 2014).

Discharges to surface waters of the US is regulated by the Clean Water Act (CWA). The CWA is designed to reduce point source pollution to enable the navigable waters of the US to be both “fishable and swimmable.” Under the CWA any facility wishing to discharge into the surface waters of the US must first obtain a permit under the National Pollution Discharge Elimination System (NPDES). NPDES permits are basically licenses to pollute with stipulations on the character and concentrations of pollutants that can be discharged into surface waters based on either current available technologies for pollutant reduction or water quality standards of the receiving waters. Currently, the EPA has a “zero-discharge” policy for direct discharges of fracking waste water to navigable waters. Discharge of fracking waste water into surface waters of the US can be permitted if proper treatment is first applied to the waste water. Treatment of fracking waste water can occur at either privately owned Centralized Waste Treatment (CWT) facilities or Publically Owned Treatment Works (POTW). While the EPA has several limitations regarding the treated discharge of fracking waste water, the agency has also granted several exclusions that may endanger the quality of surface waters held in the public common. These exclusions include the inapplicability of effluent limitations to CWTs which only treat fracking waste water (or another single waste category) *or* transport the wastes from off-site through a pipeline into the CWT (Gaba, 2014). These exclusions may create a potential for fracking waste water above EPA effluent guidelines to enter into surface waters.

Discharges of treated fracking waste water can also be accomplished through the use of POTWs. Some caveats of this form of indirect discharge include that the influent waste water cannot impede the operation of the POTW and that the POTW is equipped to handle the pollutants in the waste water (e.g. the waste water will not simply pass through the POTW). In cases where the POTW is found to be insufficient in reducing the pollutant load of the influent waste water prior to discharge, pretreatment standards may be developed to remove pollutants before entering the POTW. EPA is currently conducting studies to help develop pretreatment standards for fracking waste water being disposed of via a POTW, the standards are due for release sometime in 2015 (Gaba, 2014).

The 1987 Water Quality Act as well as the 2005 Energy Policy Act amended the CWA to allow for the construction and operation of oil and gas wells without the storm water discharge permits required by the CWA. While this permit deals solely with uncontaminated storm runoff from these sites, these exemptions will undoubtedly effect local streams and water ways in the vicinity of the well pads and may cause increased erosion in instances where the well operators do not take it upon themselves to implement best management practices (BMPs) for erosion and runoff control.

Federal Law	Applicable to Oil and Gas Development	Exemptions or Limitations	Source of Exemption Exemption or Limitation
Safe Drinking Water Act	• Underground Injection Control Program • Imminent and Substantial Endangerment Provision	• Hydraulic fracturing fluids other than diesel fuels do not require Underground Injection Control Permit	Statutory – 2005 Energy Policy Act
Clean Water Act	• National Pollutant Discharge Elimination System program • Spill reporting and spill prevention and response planning requirements	• Federal stormwater permits not required for uncontaminated stormwater at oil and gas construction or well sites	Statutory - 1987 Water Quality Act and 2005 Energy Policy Act
Resource Conservation and Recovery Act	• Non-exempt wastes present at well sites may be regulated as hazardous • Imminent and Substantial Endangerment Provision	• Oil and gas exploration and production wastes not regulated as hazardous waste	1988 Regulatory/EPA decision
Comprehensive Environmental Response, Compensation, and Liability Act	• Hazardous substance release reporting • Imminent and Substantial Endangerment Provision for releases of a pollutant or contaminant	• Liability and reporting provisions do not apply to injections of fluids authorized by state law for production, enhanced recover, or produced water • Petroleum releases not covered	Statutory – 1980
Emergency Planning and Community Right-to-Know Act	• Reporting on use, inventories, and releases into the environment of hazardous and toxic chemicals above threshold quantities	• Oil and gas well operations not required to report releases of listed chemicals to Toxics Release Inventory	1997 Regulatory/EPA decision

Figure 5: A Summation of US Federal Environmental Laws as they relate to HVHF
Source: Tip of the Mitt Watershed Council of Northern Michigan –
www.watershedcouncil.org/learn/hydraulic-fracturing/regulations-and-exemptions

E. ECONOMIC EFFECTS OF HVHF

The difficulty in assessing the economic value of unconventional oil and gas extraction is due to many factors, including the sharp variations in market value, a transient workforce, centralized drilling companies and also the affiliations of researchers with drilling companies. To date the vast majority of economic research conducted on the economic benefits unconventional gas and oil extraction has been funded by organizations that would greatly benefit by the expansion of this industry. Kinnanan discusses shortfalls of 6 of these extraction-affiliated economic publishings and offers that they could be corrected by: "1) including better assumptions of when and where households spend windfall gains 2) clarifying the process used to determine where suppliers to the industry and royalty earnings households are located (in state or not), and 3) developing a more appropriate econometric model to estimate well drilling as a function of current price and other relevant variables," (2011). Additionally, Kinnanan states that "if institutional affiliation increases the exposure of these reports, then policy makers and other readers may be misguided by questionable economic estimates."

It is clear that unconventional extraction of oil and gas does generate some degree of wealth to both communities and industries while increasing domestic energy production despite the "questionable economic estimates" mentioned above. The difficulty in assessing the degree of wealth lies in the ability of economic researchers to quantify both the benefits and the costs (both internal and external) of hydraulic fracturing. Additionally, the economic advantages of HF can be disproportionately scattered across a community or region, causing several additional problems to occur, "…economic benefits, as well as risks, occur all along the supply and distribution chain, not just within the drilling region, and also…drilling regions may not see job creation and economic benefits proportionate to their risks," (Christopherson and Rightor, 2015).

An analysis of a "typical" boom and bust cycle for a community may be helpful in refining economic benefits and risks. As a drilling company arrives in a shale gas region, a small surge in population brings a moderate increase in demand for local goods and services, which may in turn drive up prices for consumer goods and create some low-paying service jobs (Marchand, 2012). Relatively few skilled craftspeople/laborers will see an increase in work as most of the highly technical drilling will be performed by industry professionals from outside the community (Weber, 2012). Land owners will receive payments from the extraction companies for signing leases; however, data detailing how much of the royalty payments will be spent locally vary significantly (Kinnanan, 2011). Local governments may receive increased revenues from excise taxes, although these may be dwarfed in comparison to the increased costs in public services needed to support the additional population (i.e. police, fire, and EMS personnel as well as additional infrastructure such as roads and bridges). As the drilling process completes and the wells begin their production phase the majority of the oil and gas workforce leaves the community for the next site and economic contraction begins. As unconventional shale wells may require re-fracked every 3-5 years, several instances of this boom and bust cycle may occur of the extraction lifetimes of the wells. Once the resource has been locally depleted, royalty monies stop, and the population continues to diminish if no other economy is available. "After the boom ends and the drilling crews and the service providers depart, the region may have a smaller population and a poorer economy than before the extraction industry moved in," (Feser and Sweeney, 1999).

While the lack of empirical evidence in the above deliberation on the economic effects (both benefits and costs) of hydraulic fracturing of shale formations is apparent, the compilation of data leading toward a decisive conclusion on this topic is of great importance. Already HF of shale formations has led to the polarization of both scientific and actual, physical communities. If proven empirical evidence regarding the socio-economic effects of this resource extraction technique can be presented, then perhaps the rational members of both of these communities can decide on the best way forward for all involved.

VI. DISCUSSION

While the actual process of HVHF is nothing short of a technological marvel; the procedures used during this process, as well as the amount of oversight and regulation allotted to HVHF is very likely in need of revision.

Near the time of the submitting of this paper, many noteworthy happenings within the scope of this document were taking place. Most notably was the announcement of Federal Regulations governing the HVHF of Federal lands of the US. These regulations would mandate the disclosure of HFF constituents, increase well construction inspections and increase oversight in the proper disposal of HVHF waste waters on federally owned lands of the US (approximately 10% of all shale plays considered for HVHF according to the Associated Press). This piece of legislature is currently being fought by both environmentalists and industry representatives, as well as liberal and conservative politicians for being too lax and too restrictive: respectively.

VII. CONCLUSION

It was the intent of this paper to highlight both the positive and negative aspects of the newly implemented high volume hydraulic fracturing (HVHF) technique with regard to its implications in the economy, on the environment and in social spheres. It was the conclusion of several of the papers cited in this paper, as well as the opinion of the author, that further scientific research is needed in order to form a more decisive conclusion as to the whether the total gains of HVHF outweigh the total risks of HVHF *or not*. The HVHF risks of decreased water quality, decreased water supply, contaminated soil, possible increased air pollution, noise pollution, habitat fragmentation and economic bust have been contrasted to the promise of increased domestic energy production, decreased number of conventional wells, increased jobs, possible decreased air pollution and economic boom. Cases of all of these instance of both risk and benefit have been, at least in part, scientifically documented; however, the conclusion as to whether HVHF should continue or not must rest on the cumulative results of further scientific studies. Scientific studies in each of the aforementioned areas of risk and benefit should be completed, where reasonably possible, in their entirety prior to further drilling. Without this unbiased scientific evidence on the total sum of costs and benefits (internal and external) of HVHF; under-informed communities, whether from good fortune or through misguidance, will either allow or ban this technology. Communities overlying shale plays rich in fossil fuels should not be made to choose between economic prosperity and the environmental and social health of the community without first being given information on the likely long-term realities of their choice.

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