Available online at www.worldscientificnews.com

World Scientific News

WSN 40 (2016) 58-92 EISSN 2392-2192

Hydraulic Fracturing; Environmental Issue

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ABSTRACT

Environment is the integrated system, each and every factor of which is dependent on the other. Marine ecosystems are very important for the overall health of both marine and terrestrial environments. According to the World Resource Center, coastal habitats alone account for approximately 1/3 of all marine biological productivity, and estuarine ecosystems (i.e., salt marshes, seagrasses, mangrove forests) are among the most productive regions on the planet. In addition, other marine ecosystems such as coral reefs, provide food and shelter to the highest levels of marine diversity in the world. Marine ecosystems usually have a large biodiversity and are therefore thought to have a good resistance against invasive species. However, exceptions have been observed, and the mechanisms responsible in determining the success of an invasion are not yet clear. Changes among the factors an any ecosystem are permissible up to some extent. Induced hydraulic fracturing (hydrofracturing, also commonly known as fracking or fraccing) is a mining technique in which a liquid (in most cases water) is mixed with sand and chemicals and the resultant mixture injected at high pressure into a wellbore. This creates small fractures in the deep rock formations, typically less than 1mm wide, along which gas, petroleum and brine may migrate to the well. Hydraulic pressure is removed from the well, then small grains of proppant (sand or aluminium oxide) hold these fractures open once the rock achieves equilibrium. The technique is very common in wells for shale gas, tight gas, tight oil, and coal seam gas and hard rock wells. This well stimulation is usually conducted once in the life of the well and greatly enhances fluid removal and well productivity, but there has been an increasing trend towards multiple hydraulic fracturing as production declines. The first experimental use of hydraulic fracturing was in 1947, and the first commercially successful applications were in 1949. As of 2012, 2.5 million hydraulic fracturing jobs have been performed on oil and gas wells worldwide, more than one million of them in the United States. Proponents of hydraulic fracturing point to the economic benefits from the vast amounts of formerly inaccessible hydrocarbons the process can extract. Opponents of hydraulic fracturing point to environmental risks, including contamination of ground water, depletion of fresh water, contamination of the air, noise pollution, the migration of gases and hydraulic fracturing chemicals to the surface, surface contamination from spills and flow-back, and the possible health effects of these. There are increases in seismic activity, mostly associated with deep injection disposal of flowback and produced brine from hydraulically fractured wells. For these reasons hydraulic fracturing has come under international scrutiny, with some countries protecting it, and others suspending or banning it. Some of those countries, including most notably the United Kingdom, have recently lifted their bans, choosing to focus on regulation instead of outright prohibition. The European Union is in the process of applying regulation to permit this to take place.

Keywords**:** Fraccing; Environmental Risk; Aquatic Ecosystem; Proppant; Leakoff

1. INTRODUCTION

Marine ecosystems are among the largest of Earth's aquatic ecosystems. They include oceans, salt marsh and intertidal ecology, estuaries and lagoons, mangroves and coral reefs, the deep sea and the sea floor. They can be contrasted with freshwater ecosystems, which have a lower salt content. Marine waters cover two-thirds of the surface of the Earth. Such places are considered ecosystems because the plant life supports the animal life and vice-versa.

Fracturing in rocks at depth tends to be suppressed by the confining pressure, due to the immense load caused by the overlying rock strata and the cementation of the formation. This is particularly so in the case of "tensile" (Mode 1) fractures, which require the walls of the fracture to move apart, working against this confining pressure. Hydraulic fracturing occurs when the effective stress is overcome sufficiently by an increase in the pressure of fluids within the rock, such that the minimum principal stress becomes tensile and exceeds the tensile strength of the material.[13][14]

Fractures formed in this way will in the main be oriented in the plane perpendicular to the minimum principal stress and for this reason induced hydraulic fractures in well bores are sometimes used to determine the orientation of stresses.[15] In natural examples, such as dikes or vein-filled fractures, the orientations can be used to infer past states of stress.[16] Most mineral vein systems are a result of repeated hydraulic fracturing of the rock during periods of relatively high pore fluid pressure.

This is particularly noticeable in the case of "crack-seal" veins, where the vein material can be seen to have been added in a series of discrete fracturing events, with extra vein material deposited on each occasion.[17] One mechanism to demonstrate such examples of long-lasting repeated fracturing is the effect of seismic activity, in which the stress levels rise and fall episodically and large volumes of connate water may be expelled from fluid-filled fractures during earthquakes.

This process is referred to as "seismic pumping".[18] Low-level minor intrusions such as dikes propagate through the crust in the form of fluid-filled cracks, although in this case the fluid is magma. In sedimentary rocks with a significant water content the fluid at the propagating fracture tip will be steam.[19]

2. HISTORY OF FRACTURING

Fracturing as a method to stimulate shallow, hard rock oil wells dates back to the 1860s. It was applied by oil producers in the US states of Pennsylvania, New York, Kentucky, and West Virginia by using liquid and later also solidified nitroglycerin. Later, the same method was applied to water and gas wells. The idea to use acid as a nonexplosive fluid for well stimulation was introduced in the 1930s. Due to acid etching, fractures would not close completely and therefore productivity was increased.[20]

The relationship between well performance and treatment pressures was studied by Floyd Farris of Stanolind Oil and Gas Corporation. This study became a basis of the first hydraulic fracturing experiment, which was conducted in 1947 at the Hugoton gas field in Grant County of southwestern Kansas by Stanolind.[1][21] For the well treatment 1,000 US gallons (3,800 l; 830 imp gal) of gelled gasoline (essentially napalm) and sand from the Arkansas River was injected into the gas-producing limestone formation at 2,400 feet (730 m). The experiment was not very successful as deliverability of the well did not change appreciably. The process was further described by J.B. Clark of Stanolind in his paper published in 1948. A patent on this process was issued in 1949 and an exclusive license was granted to the Halliburton Oil Well Cementing Company. On March 17, 1949, Halliburton performed the first two commercial hydraulic fracturing treatments in Stephens County, Oklahoma, and Archer County, Texas.[21] Since then, hydraulic fracturing has been used to stimulate approximately a million oil and gas wells[22] in various geologic regimes with good success. In contrast with the large-scale hydraulic fracturing used in low-permeability formations, small hydraulic fracturing treatments are commonly used in high-permeability formations to remedy skin damage at the rock-borehole interface. In such cases the fracturing may extend only a few feet from the borehole.[23]

In the Soviet Union, the first hydraulic proppant fracturing was carried out in 1952. Other countries in Europe and Northern Africa to use hydraulic fracturing included Norway, Poland, Czechoslovakia, Yugoslavia, Hungary, Austria, France, Italy, Bulgaria, Romania, Turkey, Tunisia, and Algeria.[24]

Pan American Petroleum applied the first massive hydraulic fracturing (also known as high-volume hydraulic fracturing) treatment in Stephens County, Oklahoma, USA in 1968. The definition of massive hydraulic fracturing varies somewhat, but is generally used for treatments injecting greater than about 150 short tons, or approximately 330,000 pounds (136 metric tonnes), of proppant.[25]

American geologists became increasingly aware that there were huge volumes of gas-saturated sandstones with permeability too low (generally less than 0.1 millidarcy) to recover the gas economically.[25] Starting in 1973, massive hydraulic fracturing was used in thousands of gas wells in the San Juan Basin, Denver Basin,[26] the Piceance Basin,[27] and the Green River Basin, and in other hard rock formations of the western US. Other tight sandstones in the US made economic by massive hydraulic fracturing were the Clinton-Medina Sandstone, and Cotton Valley Sandstone.[25]

Massive hydraulic fracturing quickly spread in the late 1970s to western Canada, Rotliegend and Carboniferous gas-bearing sandstones in Germany, Netherlands onshore and offshore gas fields, and the United Kingdom sector of the North Sea.[24]

Horizontal oil or gas wells were unusual until the 1980s. Then in the late 1980s, operators in Texas began completing thousands of oil wells by drilling horizontally in the

Austin Chalk, and giving massive slickwater hydraulic fracturing treatments to the wellbores. Horizontal wells proved much more effective than vertical wells in producing oil from the tight chalk;[28] the shale runs horizontally so a horizontal well reached much more of the resource.[29] In 1991, the first horizontal well was drilled in the Barnett Shale[29] and in 1996 slickwater fluids were introduced.[29]

Due to shale's high porosity and low permeability, technological research, development and demonstration were necessary before hydraulic fracturing could be commercially applied to shale gas deposits. In 1976 the United States government started the Eastern Gas Shales Project, a set of dozens of public-private hydraulic fracturing pilot demonstration projects.[30] During the same period, the Gas Research Institute, a gas industry research consortium, received approval for research and funding from the Federal Energy Regulatory Commission.[31]

In 1997, taking the slickwater fracturing technique used in East Texas by Union Pacific Resources, now part of Anadarko Petroleum Corporation, Mitchell Energy, now part of Devon Energy, learned how to use the technique in the Barnett Shale of north Texas, which made shale gas extraction widely economical.[32][33][34] George P. Mitchell has been called the "father of fracking" because of his role in applying it in shales.[35]

As of 2013, massive hydraulic fracturing is being applied on a commercial scale to shales in the United States, Canada, and China. Several countries are planning to use hydraulic fracturing for unconventional oil and gas production.[36][37][38]

3. PROCESS OF HYDRAULIC FRACTURING

According to the United States Environmental Protection Agency (EPA) *hydraulic fracturing* is a process to stimulate a natural gas, oil, or geothermal energy well to maximize the extraction. The broader process, however, is defined by EPA as including the acquisition of source water, well construction, well stimulation, and waste disposal.[39]

A hydraulic fracture is formed by pumping the fracturing fluid into the wellbore at a rate sufficient to increase pressure downhole at the target zone (determined by the location of the well casing perforations) to exceed that of the fracture gradient (pressure gradient) of the rock.[40] The fracture gradient is defined as the pressure increase per unit of the depth due to its density and it is usually measured in pounds per square inch per foot or bars per meter. The rock cracks and the fracture fluid continues further into the rock, extending the crack still further, and so on. Fractures are localized because of pressure drop off with frictional loss, which is attributed to the distance from the well. Operators typically try to maintain "fracture width", or slow its decline, following treatment by introducing into the injected fluid a proppant – a material such as grains of sand, ceramic, or other particulates, that prevent the fractures from closing when the injection is stopped and the pressure of the fluid is removed. Consideration of proppant strengths and prevention of proppant failure becomes more important at greater depths where pressure and stresses on fractures are higher. The propped fracture is permeable enough to allow the flow of formation fluids to the well. Formation fluids include gas, oil, salt water and fluids introduced to the formation during completion of the well during fracturing.[40]

During the process, fracturing fluid leakoff (loss of fracturing fluid from the fracture channel into the surrounding permeable rock) occurs. If not controlled properly, it can exceed

70% of the injected volume. This may result in formation matrix damage, adverse formation fluid interactions, or altered fracture geometry and thereby decreased production efficiency.[41]

The location of one or more fractures along the length of the borehole is strictly controlled by various methods that create or seal off holes in the side of the wellbore. Hydraulic fracturing is performed in cased wellbores and the zones to be fractured are accessed by perforating the casing at those locations.[42]

Hydraulic-fracturing equipment used in oil and natural gas fields usually consists of a slurry blender, one or more high-pressure, high-volume fracturing pumps (typically powerful triplex or quintuplex pumps) and a monitoring unit. Associated equipment includes fracturing tanks, one or more units for storage and handling of proppant, high-pressure treating iron, a chemical additive unit (used to accurately monitor chemical addition), low-pressure flexible hoses, and many gauges and meters for flow rate, fluid density, and treating pressure.[43] Chemical additives are typically 0.5% percent of the total fluid volume. Fracturing equipment operates over a range of pressures and injection rates, and can reach up to 100 megapascals (15,000 psi) and 265 litres per second (9.4 cu ft/s) (100 barrels per minute).[44]

A distinction can be made between conventional or low-volume hydraulic fracturing used to stimulate high-permeability reservoirs to frac a single well, and unconventional or high-volume hydraulic fracturing, used in the completion of tight gas and shale gas wells as unconventional wells are deeper and require higher pressures than conventional vertical wells.[45] In addition to hydraulic fracturing of vertical wells, it is also performed in horizontal wells. When done in already highly permeable reservoirs such as sandstone-based wells, the technique is known as "well stimulation".[46]

Horizontal drilling involves wellbores where the terminal drillhole is completed as a "lateral" that extends parallel with the rock layer containing the substance to be extracted. For example, laterals extend 1,500 to 5,000 feet (460 to 1,520 m) in the Barnett Shale basin in Texas, and up to 10,000 feet (3,000 m) in the Bakken formation in North Dakota. In contrast, a vertical well only accesses the thickness of the rock layer, typically 50-300 feet (15-91 m). Horizontal drilling also reduces surface disruptions as fewer wells are required to access a given volume of reservoir rock. Drilling usually induces damage to the pore space at the wellbore wall, reducing the permeability at and near the wellbore. This reduces flow into the borehole from the surrounding rock formation, and partially seals off the borehole from the surrounding rock. Hydraulic fracturing can be used to restore permeability,[47] but is not typically administered in this way.

4. FRACTURING FLUIDS IN THE UNITED STATES

High-pressure fracture fluid is injected into the wellbore, with the pressure above the fracture gradient of the rock. The two main purposes of fracturing fluid is to extend fractures, add lubrication, change gel strength and to carry proppant into the formation, the purpose of which is to stay there without damaging the formation or production of the well. Two methods of transporting the proppant in the fluid are used – high-rate and high-viscosity. High-viscosity fracturing tends to cause large dominant fractures, while high-rate (slickwater) fracturing causes small spread-out micro-fractures.

This fracture fluid contains water-soluble gelling agents (such as guar gum) which increase viscosity and efficiently deliver the proppant into the formation.[48]

The fluid injected into the rock is typically a slurry of water, proppants, and chemical additives.[49] Additionally, gels, foams, and compressed gases, including nitrogen, carbon dioxide and air can be injected. Typically, of the fracturing fluid 90% is water and 9.5% is sand with the chemical additives accounting to about 0.5%.[40][50][51] However, fracturing fluids have been developed in which the use of water has been made unnecessary, using liquefied petroleum gas (LPG) and propane.[52]

A proppant is a material that will keep an induced hydraulic fracture open, during or following a fracturing treatment, and can be gel, foam, or slickwater-based. Fluids make tradeoffs in such material properties as viscosity, where more viscous fluids can carry more concentrated proppant; the energy or pressure demands to maintain a certain flux pump rate (flow velocity) that will conduct the proppant appropriately; pH, various rheological factors, among others. Types of proppant include silica sand, resin-coated sand, and man-made ceramics. These vary depending on the type of permeability or grain strength needed. The most commonly used proppant is silica sand, though proppants of uniform size and shape, such as a ceramic proppant, is believed to be more effective. Due to a higher porosity within the fracture, a greater amount of oil and natural gas is liberated.[53]

The fracturing fluid varies in composition depending on the type of fracturing used, the conditions of the specific well being fractured, and the water characteristics. A typical fracture treatment uses between 3 and 12 additive chemicals.[40] Although there may be unconventional fracturing fluids, the more typically used chemical additives can include one or more of the following:

- Acids-hydrochloric acid or acetic acid is used in the pre-fracturing stage for cleaning the perforations and initiating fissure in the near-wellbore rock.[51]
- Sodium chloride (salt) - delays breakdown of the gel polymer chains.[51]
- Polyacrylamide and other friction reducers - Decrease turbulence in fluid flow decreasing pipe friction, thus allowing the pumps to pump at a higher rate without having greater pressure on the surface.[51]
- Ethylene glycol - prevents formation of scale deposits in the pipe.[51]
- Borate salts - used for maintaining fluid viscosity during the temperature increase.[51]
- Sodium and potassium carbonates - used for maintaining effectiveness of crosslinkers.[51]
- Glutaraldehyde - used as disinfectant of the water (bacteria elimination).[51]
- Guar gum and other water - soluble gelling agents - increases viscosity of the fracturing fluid to deliver more efficiently the proppant into the formation.[48][51]
- Citric acid - used for corrosion prevention.
- Isopropanol - increases the viscosity of the fracture fluid.[51]

The most common chemical used for hydraulic fracturing in the United States in 2005–2009 was methanol, while some other most widely used chemicals were isopropyl alcohol, 2-butoxyethanol, and ethylene glycol.[54]

Typical fluid types are:

- Conventional linear gels. These gels are cellulose derivatives (carboxymethyl cellulose, hydroxyethyl cellulose, carboxymethyl hydroxyethyl cellulose, hydroxypropyl cellulose, methyl hydroxyl ethyl cellulose), guar or its derivatives (hydroxypropyl guar, carboxymethyl hydroxypropyl guar)-based, with other chemicals providing the necessary chemistry for the desired results.
- Borate-crosslinked fluids. These are guar-based fluids cross-linked with boron ions (from aqueous borax/boric acid solution). These gels have higher viscosity at pH 9 onwards and are used to carry proppants. After the fracturing job the pH is reduced to 3-4 so that the cross-links are broken and the gel is less viscous and can be pumped out.
- Organometallic-crosslinked fluids zirconium, chromium, antimony, titanium salts are known to crosslink the guar-based gels. The crosslinking mechanism is not reversible. So once the proppant is pumped down along with the cross-linked gel, the fracturing part is done. The gels are broken down with appropriate breakers.[48]
- Aluminium phosphate-ester oil gels. Aluminium phosphate and ester oils are slurried to form cross-linked gel. These are one of the first known gelling systems.

For slickwater it is common to include sweeps or a reduction in the proppant concentration temporarily to ensure the well is not overwhelmed with proppant causing a screen-off.[55] As the fracturing process proceeds, viscosity reducing agents such as oxidizers and enzyme breakers are sometimes then added to the fracturing fluid to deactivate the gelling agents and encourage flowback.[48] The oxidizer reacts with the gel to break it down, reducing the fluid's viscosity and ensuring that no proppant is pulled from the formation. An enzyme acts as a catalyst for the breaking down of the gel. Sometimes pH modifiers are used to break down the crosslink at the end of a hydraulic fracturing job, since many require a pH buffer system to stay viscous.[55] At the end of the job the well is commonly flushed with water (sometimes blended with a friction reducing chemical) under pressure. Injected fluid is to some degree recovered and is managed by several methods, such as underground injection control, treatment and discharge, recycling, or temporary storage in pits or containers while new technology is continually being developed and improved to better handle waste water and improve re-usability.[40]

Fracture monitoring -

Measurements of the pressure and rate during the growth of a hydraulic fracture, as well as knowing the properties of the fluid and proppant being injected into the well provides the most common and simplest method of monitoring a hydraulic fracture treatment. This data, along with knowledge of the underground geology can be used to model information such as length, width and conductivity of a propped fracture.[40]

Injection of radioactive tracers, along with the other substances in hydraulic-fracturing fluid, is sometimes used to determine the injection profile and location of fractures created by hydraulic fracturing.[56] The radiotracer is chosen to have the readily detectable radiation, appropriate chemical properties, and a half life and toxicity level that will minimize initial and residual contamination.[57]

Radioactive isotopes chemically bonded to glass (sand) and/or resin beads may also be injected to track fractures.[58] For example, plastic pellets coated with 10 GBq of Ag-110mm may be added to the proppant or sand may be labelled with Ir-192 so that the proppant's progress can be monitored.[57]

Radiotracers such as Tc-99m and I-131 are also used to measure flow rates.[57] The Nuclear Regulatory Commission publishes guidelines which list a wide range of radioactive materials in solid, liquid and gaseous forms that may be used as tracers and limit the amount that may be used per injection and per well of each radionuclide.[58]

Microseismic monitoring -

For more advanced applications, microseismic monitoring is sometimes used to estimate the size and orientation of hydraulically induced fractures. Microseismic activity is measured by placing an array of geophones in a nearby wellbore. By mapping the location of any small seismic events associated with the growing hydraulic fracture, the approximate geometry of the fracture is inferred. Tiltmeter arrays, deployed on the surface or down a well, provide another technology for monitoring the strains produced by hydraulic fracturing.[59]

Microseismic mapping is very similar geophysically to seismology. In earthquake seismology seismometers scattered on or near the surface of the earth record S-waves and P-waves that are released during an earthquake event. This allows for the motion along the fault plane to be estimated and its location in the earth’s subsurface mapped. During formation stimulation by hydraulic fracturing an increase in the formation stress proportional to the net fracturing pressure as well as an increase in pore pressure due to leakoff takes place.[60] Tensile stresses are generated ahead of the fracture/cracks’ tip which generates large amounts of shear stress.

The increase in pore water pressure and formation stress combine and affect the weakness (natural fractures, joints, and bedding planes) near the hydraulic fracture. Dilatational and compressive reactions occur and emit seismic energy detectable by highly sensitive geophones placed in nearby wells or on the surface.[61]

Different methods have different location errors and advantages. Accuracy of microseismic event locations is dependent on the signal to noise ratio and the distribution of the receiving sensors. For a surface array location accuracy of events located by seismic inversion is improved by sensors placed in multiple azimuths from the monitored borehole. In a downhole array location accuracy of events is improved by being close to the monitored borehole (high signal to noise ratio).

Monitoring of microseismic events induced by reservoir stimulation has become a key aspect in evaluation of hydraulic fractures and their optimization. The main goal of hydraulic fracture monitoring is to completely characterize the induced fracture structure and distribution of conductivity within a formation. This is done by first understanding the fracture structure.

Geomechanical analysis, such as understanding the material properties, in-situ conditions and geometries involved will help with this by providing a better definition of the environment in which the hydraulic fracture network propagates.[62] The next task is to know the location of proppant within the induced fracture and the distribution of fracture conductivity. This can be done using multiple types of techniques and finally, further develop a reservoir model than can accurately predict well performance.

Horizontal completions -

Since the early 2000s, advances in drilling and completion technology have made drilling horizontal wellbores much more economical. Horizontal wellbores allow for far greater exposure to a formation than a conventional vertical wellbore. This is particularly useful in shale formations which do not have sufficient permeability to produce economically with a vertical well. Such wells when drilled onshore are now usually hydraulically fractured in a number of stages, especially in North America. The type of wellbore completion used will affect how many times the formation is fractured, and at what locations along the horizontal section of the wellbore.[63]

In North America, shale reservoirs such as the Bakken, Barnett, Montney, Haynesville, Marcellus, and most recently the Eagle Ford, Niobrara and Utica shales are drilled, completed and fractured using this method. The method by which the fractures are placed along the wellbore is most commonly achieved by one of two methods, known as "plug and perf" and "sliding sleeve".[64]

The wellbore for a plug and perf job is generally composed of standard joints of steel casing, either cemented or uncemented, which is set in place at the conclusion of the drilling process. Once the drilling rig has been removed, a wireline truck is used to perforate near the end of the well, following which a fracturing job is pumped (commonly called a stage). Once the stage is finished, the wireline truck will set a plug in the well to temporarily seal off that section, and then perforate the next section of the wellbore. Another stage is then pumped, and the process is repeated as necessary along the entire length of the horizontal part of the wellbore.[65]

The wellbore for the sliding sleeve technique is different in that the sliding sleeves are included at set spacings in the steel casing at the time it is set in place. The sliding sleeves are usually all closed at this time. When the well is ready to be fractured, using one of several activation techniques, the bottom sliding sleeve is opened and the first stage gets pumped. Once finished, the next sleeve is opened which concurrently isolates the first stage, and the process repeats. For the sliding sleeve method, wireline is usually not required.

These completion techniques may allow for more than 30 stages to be pumped into the horizontal section of a single well if required, which is far more than would typically be pumped into a vertical well.[66]

5. USES OF HYDRAULIC FRACTURING

The technique of hydraulic fracturing is used to increase the rate at which fluids, such as petroleum, water, or natural gas can be recovered from subterranean natural reservoirs. Reservoirs are typically porous sandstones, limestones or dolomite rocks, but also include "unconventional reservoirs" such as shale rock or coal beds. Hydraulic fracturing enables the production of natural gas and oil from rock formations deep below the earth's surface (generally 5,000–20,000 feet (1,500–6,100 m)), which is typically greatly below groundwater reservoirs of basins if present. At such depth, there may not be sufficient permeability or reservoir pressure to allow natural gas and oil to flow from the rock into the wellbore at economic rates. Thus, creating conductive fractures in the rock is pivotal to extract gas from shale reservoirs because of the extremely low natural permeability of shale, which is measured in the microdarcy to nanodarcy range.[67]

Fractures provide a conductive path connecting a larger volume of the reservoir to the well. So-called "super fracking," which creates cracks deeper in the rock formation to release more oil and gas, will increase efficiency of hydraulic fracturing.[68] The yield for a typical shale gas well generally falls off after the first year or two, although the full producing life of a well can last several decades.[69]

While the main industrial use of hydraulic fracturing is in arousing production from oil and gas wells,[70][71][46] hydraulic fracturing is also applied:

- To stimulate groundwater wells[72]
- To precondition or induce rock to cave in mining[73]
- As a means of enhancing waste remediation processes, usually hydrocarbon waste or spills[74]
- To dispose of waste by injection into deep rock formations[75]
- As a method to measure the stress in the Earth[76]
- For heat extraction to produce electricity in enhanced geothermal systems[77]
- To increase injection rates for geologic sequestration of CO_2 [78]

Since the late 1970s, hydraulic fracturing has been used in some cases to increase the yield of drinking water from wells in a number of countries, including the US, Australia, and South Africa.[79][80][81]

6. IMPACTS OF HYDRAULIC FRACTURING

Hydraulic fracturing has been seen as one of the key methods of extracting unconventional oil and gas resources. According to the International Energy Agency, the remaining technically recoverable resources of shale gas are estimated to amount to 208 trillion cubic metres (208,000 km^3), tight gas to 76 trillion cubic metres (76,000 km^3), and coalbed methane to 47 trillion cubic metres (47,000 km^3). As a rule, formations of these resources have lower permeability than conventional gas formations. Therefore depending on the geological characteristics of the formation, specific technologies (such as hydraulic fracturing) are required. Although there are also other methods to extract these resources, such as conventional drilling or horizontal drilling, hydraulic fracturing is one of the key methods making their extraction economically viable. The multi-stage fracturing technique has facilitated the development of shale gas and light tight oil production in the United States and is believed to do so in the other countries with unconventional hydrocarbon resources.[5]

The National Petroleum Council estimates that hydraulic fracturing will eventually account for nearly 70% of natural gas development in North America.[82] Hydraulic fracturing and horizontal drilling apply the latest technologies and make it commercially viable to recover shale gas and oil. In the United States, 45% of domestic natural gas production and 17% of oil production would be lost within 5 years without usage of hydraulic fracturing.[83]

U.S.-based refineries have gained a competitive edge with their access to relatively inexpensive shale oil and Canadian crude. The U.S. is exporting more refined petroleum products, and also more liquified petroleum gas (LP gas). LP gas is produced from hydrocarbons called natural gas liquids, released by the hydraulic fracturing of petroliferous shale, in a variety of shale gas that's relatively easy to export. Propane, for example, costs around $620 a ton in the U.S. compared with more than $1,000 a ton in China, as of early 2014. Japan, for instance, is importing extra LP gas to fuel power plants, replacing idled nuclear plants. Trafigura Beheer BV, the third-largest independent trader of crude oil and refined products, said last month that "growth in U.S. shale production has turned the distillates market on its head."[84]

Some studies call into question the claim that what has been called the "shale gas revolution" has a significant macro-economic impact. A study released in the beginning of 2014 by the IDDRI shows the contrary. It demonstrates that, on the long-term as well as on the short-run, the "shale gas revolution" due to hydraulic fracturing in the United States has had very little impact on economic growth and competitiveness. It is also very unlikely to make some substantial contribution to GDP growth in the future. It would most likely be the same in Europe according to the study, despite of dramatically increased levels of production of unconventional oil and unconventional gas. Providing an optimistic hypothesis, in other words an upper estimation of shale gas effects on the level of US GDP, the study estimates the impact of hydraulic fracturing on the level of US GDP at 0.84% between 2012 and 2035, also estimating it as 0.88% of GDP growth during the period 2007-2012. Although the study found that on the very short-term, it has had a positive impact on GDP, estimated at 0.4%, due to a fall in gas prices, these effects are located and non-replicable over time ("one-off burst"). Overall, the study reads that "the US trade balance shows no sign of a large shift in competitiveness in non-petroleum and gas sectors."[85]

In Europe, using hydraulic fracturing would have very little advantages in terms of competitiveness and energy security. Indeed, for the period 2030-2035, shale gas is estimated to cover 3 to 10% of EU projected energy demand, which is not enough to have a significant impact on energetic independence and competitiveness .[85]

Hydraulic fracturing operations can damage transportation infrastructure, creating costs for local taxpayers. An article in Bloomberg BusinessWeek brought attention to the damage to rural roads caused by the heavy trucks used in hydraulic fracturing operations. Drilling companies can be contractually obligated to cover the costs of road repair. For example, in Wetzel County, one of these rural areas, residents reported that the drilling company Chesapeake "has been pretty good about road maintenance" but worry taxpayers will nevertheless bear the full costs of repair. Some companies delay making repairs while they add new wells to their drilling sites. It will cost tens of millions of dollars to fix the current road damage. This large expenditure is not something officials from Pennsylvania to Texas are prepared for. Furthermore, measures to ensure that roads are repaired don’t always include the full cost of damage, adding another burden to the taxpayers.[86]

In addition to these issues, there have been recent concerns with the accuracy of predictions about the economic potential of shale formations that would employ hydraulic fracturing as a method of extraction. A joint report by the INTEK Inc. and U.S. Energy Information Agency in 2011 stated that there are 15.4 billion barrels of recoverable oil in the Monterey Shale formation,[87] information used by a University of Southern California economic analysis that concluded that this amount of recoverable oil would add $24.6 billion a year and 2.8 million jobs to the California economy by 2020.[88] However, according to a joint report by the Post Carbon Institute (PCI) and the Physicians, Scientists, and Engineers for Healthy Energy (PSE), comprehensive technical and scientific analyses show that the recoverable sources of the Monterey Shale site are considerably less than 15.4 billion barrels.

Moreover, the 2.8 million jobs the EIA/INTEK and USC report stated are unlikely due to the local landscape, geology, and historical characteristics of the site (thicker, tighter, and more complex structures, and in decline since its peak in 1980).[89] The potential implications of such reports are of great consequence: many proponents of hydraulic fracturing at the state and federal level look to economic reports and analyses by trusted organizations and associations to make big decisions about their communities.

The economic effect of energy extraction in rural towns was classified by one study as the Boomtown Impact Model. In this model, the emergence of a boomtown in a rural area that is rich in energy resources brings short and long term economic consequences, both positive and negative. Historical energy boomtowns (for example from the days of coal and uranium plants) show rapid increases and decreases of a local population and economy where drilling sites create jobs for the present, inevitably decline, and leave numbers of citizens jobless, with lack of goods, services, and housing, and leave local businesses downtrodden when demand falls short of supply.[90] A case study in Sublette County, Wyoming found that the boomtown produced by the natural gas drilling in the area had mixed effects. There was a significant growth of jobs however the town experienced inflation and the cost of living increased.[91] The boomtown model presented in this study almost inevitably ends with an economic bust.

It has also been pointed out that economic growth for some is not guaranteed to spread to the entire community and individuals can be negatively affected if they are not able to participate in the rapid growth.[92] Reports that fail to include the uneven distribution of impacts (both positive and negative) in its estimates leave out important issues that should be addressed for optimal assessment of the values of the entire system.

Studies, and in many cases personal experience, have revealed that certain workers, businesses, and communities will have more benefit more than others, sometimes at their expense.[93] For example, landowners, drilling companies, and tourist businesses (hotels, restaurants, and shopping arenas) will be more likely to benefit than those who are subject to the noise of drilling sites, increased traffic, and "possible degradation of waterways, forests, and open space, and strains of local labor supply."[93] The accuracy and veracity of public reports responding to these complex issues are crucial to the future of the hydraulic fracturing and cannot be overstated.

A few academic studies from universities have emerged recently.[94][95] The core insights from these studies is that unconventional shale oil and gas may have the potential to dramatically alter the geography of energy production in the US. In the short run, there are significant employment effects and spillovers in counties where resource extraction is happening. One paper finds that employment in the oil and gas sector has more than doubled in counties located above shale deposits in the last 10 years, with significant spill-overs in local transport-, construction but also manufacturing sectors.[94]

The latter benefits from significantly lower energy prices, giving the US manufacturing sector a competitive edge compared to the rest of the world. On average, natural gas prices have gone down by more than 30% in counties above shale deposits compared to the rest of the US. However, some research has also highlighted that there are negative effects on house prices for properties that lie in the direct vicinity of unconventional wells.[96] This study finds that local house prices in Pennsylvania go down if the property is close to an unconventional gas well and is not connected to utility water, suggesting that the fears of ground water pollution are priced by markets.

Social impacts of Hydraulic Fracturing -

One study has linked shale gas operations to increased risks in public health and safety. A study in rural Pennsylvania found hydraulic fracturing to be associated with increases in heavy truck crashes, social disorder arrests and cases of sexually transmitted infections. In counties in rural Pennsylvania with at least one well per fifteen square miles, heavy truck crashes rose 7.2 percent. Additionally the study determined that in rural counties with heavy hydraulic fracturing operations disorderly conduct arrests rose by 17.1% while in rural counties without hydraulic fracturing operations the arrests only increased by 12.7%. Furthermore the study found that following hydraulic fracturing, the average rise in chlamydia and gonorrhea cases was 62% higher in rural counties with heavy hydraulic fracturing operations than in rural counties without these operations. It is likely that the increased rate of truck crashes, social disorder arrests and cases of sexually transmitted infections will increase public health costs in a community, but additional research is needed to fully understand the public health and safety impacts of hydraulic fracturing.[97]

Environmental impact of Hydraulic Fracturing -

Hydraulic fracturing has raised environmental concerns and is challenging the adequacy of existing regulatory regimes.[98] These concerns have included ground water contamination, risks to air quality, migration of gases and hydraulic fracturing chemicals to the surface, mishandling of waste, and the health effects of all these.[7][40][54] An additional concern is that oil obtained through hydraulic fracturing contains chemicals used in hydraulic fracturing, which may increase the rate at which rail tank cars and pipelines corrode, potentially releasing their load and its gases.[99][100]

The air emissions from hydraulic fracturing are related to methane leaks originating from wells, and emissions from the diesel or natural gas powered equipment such as compressors, drilling rigs, pumps etc.[40] Also transportation of necessary water volume for hydraulic fracturing, if done by trucks, can cause high volumes of air emissions, especially particulate matter emissions.[101] There are also reports of health problems around compressors stations[102] or drilling sites,[103] although a causal relationship was not established for the wells studied[103] and another Texas government analysis found no evidence of effects.[104]

Whether natural gas produced by hydraulic fracturing causes higher well-to-burner emissions than gas produced from conventional wells is a matter of contention. Some studies have found that hydraulic fracturing has higher emissions due to gas released during completing wells as some gas returns to the surface, together with the fracturing fluids. Depending on their treatment, the well-to-burner emissions are 3.5%–12% higher than for conventional gas, but still stand less than half the emissions of coal.[98][105][106] Methane leakage has been calculated at the rate of 1–7% with the United States Environmental Protection Agency's estimated leakage rate to be about 2.4%.[107][108]

Massive hydraulic fracturing uses traditionally between 1.2 and 3.5 million US gallons (4.5 and 13.2 Ml) of water per well, with large projects using up to 5 million US gallons (19 Ml). Additional water is used when wells are re-fractured.[48][109] An average well requires 3 to 8 million US gallons (11,000 to 30,000 m^3) of water over its lifetime.[40][109][110][111] According to the Oxford Institute for Energy Studies, greater volumes of fracturing fluids are required in Europe, where the shale depths average 1.5 times greater than in the U.S.[112]

Use of water for hydraulic fracturing can divert water from stream flow, water supplies for municipalities and industries such as power generation, as well as recreation and aquatic life.[113] The large volumes of water required for most common hydraulic fracturing methods have raised concerns for arid regions, such as Karoo in South Africa,[114] and in Pennsylvania,[115][116] and in drought-prone Texas, and Colorado in North America.[117] To provide a perspective Texas has used 110 of the 250 billion of gallons of water the United States has used from 2005 to 2013.[106] According to Environment America there are concerns for farmers competing with oil and gas for water.[106]

Some producers have developed hydraulic fracturing techniques that could reduce the need for water by re-using recycled flowback water, or using carbon dioxide, liquid propane or other gases instead of water.[98][118][119] According to researchers water used in hydraulic fractring is permanently lost to the water cycle, as it either remains in the well, is recycled (used in the fracking of new wells), or is disposed of in deep injection wells, where it is unavailable to recharge aquifers.[106] As hydraulic fracturing helps develop shale gas reserves which contributes to replacing coal usage with natural gas, by some data water saved by using natural gas combined cycle plants instead of coal steam turbine plants makes the overall water usage balance more positive.[120]

Injected fluid -

While some of the chemicals used in hydraulic fracturing are common and generally harmless, some additives used in the United States are known carcinogens.[54] Out of 2,500 hydraulic fracturing additives, more than 650 contained known or possible human carcinogens regulated under the Safe Drinking Water Act or listed as hazardous air pollutants".[54] Another 2011 study identified 632 chemicals used in United States natural gas operations, of which only 353 are well-described in the scientific literature.[121]

Well casing or cement bond failure in injection wells, have the potential to leak methane into groundwater aquifers. Wellbores used in fracturing operations also have the potential to cause oil and gas to rise and mix into freshwater aquifers, causing most immediate harm to those communities that rely on nearby local water sources.[122]

A comprehensive study in the US about the impact of hydraulic fracturing on groundwater is to be released in 2014 by the EPA. It will be the first study of this scale to address whether or not there is an impact of hydraulic fracturing on groundwater contamination,[123] previous having only shown evidence for very localized areas like in West Virginia as reported in 1987.[124]

Flowback -

Estimates of the fluid that returns to the surface with the gas range from 15-20%[125] to 30-70%. Additional fluid may return to the surface through abandoned wells or other pathways.[126] After the flowback is recovered, formation water, usually brine, may continue to flow to the surface, requiring treatment or disposal. Approaches to managing these fluids, commonly known as flowback, produced water, or wastewater, include underground injection, municipal waste water treatment plants, industrial wastewater treatment, self-contained systems at well sites or fields, and recycling to fracture future wells.[105][127][128][129] When flowback fluid is not accepted in the local state or waste water treatment facilities they can be shipped for disposal in injection wells.[106] According to Frontier Group about 100 million gallons of water was shipped from Pennsylvania to Ohio in 2011 for disposal into underground injection wells.[106]

Flowback water can be recycled, but is an expensive time- and chemical-consuming process, and can only be recycled up until it reaches a certain Total dissolved solids (TDS) concentration level. Some facilities that treat produced water cannot remove large amounts of dissolved solids, and the contents of hydraulic fracturing fluids (salt, organic compounds, and metal concentrations) can have adverse affects on the treatment.[122]

Water sources from flowback or reinjection fluid can be treated (in varying degrees of standards) and reused in oil development, for water/stream flooding, or, it has been reported, for human/animal consumption.[122] While reinjection and treatment of hydraulic fracturing fluids and flowback may be safely regulated and reused, this requires strong policy frameworks and enforcement, transparency, and oversight at the state, local, and regional level.

Methane -

A study by MIT in 2011 found that there was evidence of natural gas (methane) migration into freshwater zones in some areas, most likely as a result of substandard well completion practices, such as poor quality cementing jobs or bad casings, by a few operators.[130] 2011 studies by the Colorado School of Public Health and Duke University also pointed to methane contamination stemming from the drilling process.[131][132] Groundwater methane contamination has adverse effect on water quality and in extreme cases may lead to potential explosion.[133][131] The correlation between drilling activity and methane pollution of the drinking water has been noted; however, studies to date have not established that methane contamination is caused by hydraulic fracturing itself, rather than by other well drilling or completion practices.[134] Most recent studies make use of tests that can distinguish between the deep thermogenic methane released during gas/oil drilling, and the shallower biogenic methane that can be released during water-well drilling. While both forms of methane result from decomposition, thermogenic methane results from geothermal assistance deeper underground.[132][135]

Radioactivity and Seismicity -

In same cases hydraulic fracturing may dislodge uranium, radium, radon and thorium from formation and these substance may consist in flowback fluid.[136] Therefore there are concerns about the levels of radioactivity in wastewater from hydraulic fracturing and its potential impact on public health. Recycling this wastewater has been proposed as a partial solution, but this approach has limitations.[137]

Hydraulic fracturing routinely produces microseismic events too small to be detected except by sensitive instruments, but it sometimes produces bigger events that can be felt by local populations. These microseismic events are often used to map the horizontal and vertical extent of the fracturing.[59] As of late 2012, there have been four known instances of hydraulic fracturing, through induced seismicity, triggering quakes large enough to be felt by people: one each in the United States and Canada, and two in England.[8][138][139] The injection of waste water from oil and gas operations, including from hydraulic fracturing, into saltwater disposal wells may cause bigger low-magnitude tremors, being registered up to 3.3 (M_w).[140]

Several earthquakes in 2011, including a 4.0 magnitude quake on New Year's Eve that hit Youngstown, Ohio, are likely linked to a disposal of hydraulic fracturing wastewater,[8] according to seismologists at Columbia University.[141] Although the magnitudes of these quakes has been small, the United States Geological Survey has said that there is no guarantee that larger quakes will not occur.[142] A report in the United Kingdom concluded that hydraulic fracturing was the likely cause of two small tremors (magnitudes 2.3 and 1.4 on the Richter scale) that occurred during hydraulic fracturing of shale in April and May 2011.[143][144][145] These tremors were felt by local populations. Because of these two events, seismicity is impact mostly related to hydraulic fracturing in the UK's public opinion.[146]

In addition, the frequency of the quakes has been increasing. In 2009, there were 50 earthquakes greater than magnitude 3.0 in the area spanning Alabama and Montana, and there were 87 quakes in 2010. In 2011 there were 134 earthquakes in the same area, a six fold increase over 20th century levels.[147]

7. EFFECTS OF HYDRAULIC FRACTURING ON HEALTH

Concern has been expressed over the possible long and short term health effects of air and water contamination and radiation exposure by gas production.[136][148][149] Health consequences of concern include infertility, birth defects and cancer.[150][151][152]

A 2012 study concluded that risk prevention efforts should be directed towards reducing air emission exposures for persons living and working near wells during well completions.[153]

A study conducted in Garfield County, Colorado and published in *Endocrinology* suggested that natural gas drilling operations may result in elevated endocrine-disrupting chemical activity in surface and ground water.[151]

8. REGULATIONS OF HYDRAULIC FRACTURING

Countries using or considering to use hydraulic fracturing have implemented different regulations, including developing federal and regional legislation, and local zoning limitations.[154][155] In 2011, after public pressure France became the first nation to ban hydraulic fracturing, based on the precautionary principle as well as the principal of preventive and corrective action of environmental hazards.[10][11][156][157] The ban was upheld by an October 2013 ruling of the Constitutional Council.[158] Some other countries have placed a temporary moratorium on the practice.[159] Countries like the United Kingdom and South Africa, have lifted their bans, choosing to focus on regulation instead of outright prohibition.[160][161] Germany has announced draft regulations that would allow using hydraulic fracturing for the exploitation of shale gas deposits with the exception of wetland areas.[162]

The European Union has adopted a recommendation for minimum principles for using high-volume hydraulic fracturing.[12] Its regulatory regime requires full disclosure of all additives.[163] In the United States, the Ground Water Protection Council launched FracFocus.org, an online voluntary disclosure database for hydraulic fracturing fluids funded by oil and gas trade groups and the U.S. Department of Energy.[164][165] Hydraulic fracturing is excluded from the Safe Drinking Water Act's underground injection control's regulation, except when diesel fuel is used. The EPA assures surveillance of the issuance of drilling permits when diesel fuel is employed.[166]

Regulatory approaches to evaluating and managing hydraulic fracturing impacts -

The main tool used by this approach is risk assessment. A risk assessment method, based on experimenting and assessing risk ex-post, once the technology is in place. In the context of hydraulic fracturing, it means that drilling permits are issued and exploitation conducted before the potential risks on the environment and human health are known. The risk-based approach mainly relies on a discourse that sacralizes technological innovations as an intrinsic good, and the analysis of such innovations, such as hydraulic fracturing, is made on a sole cost-benefit framework, which does not allow prevention or ex-ante debates on the use of the technology.[167] This is also referred to as "learning-by-doing".[146] A risk assessment method has for instance led to regulations that exist in the hydraulic fracturing in the United States (EPA will release its study on the impact of hydraulic fracturing on groundwater in 2014, though hydraulic fracturing has been used for more than 60 years. Commissions that have been implemented in the US to regulate the use of hydraulic fracturing have been created after hydraulic fracturing had started in their area of regulation. This is for instance the case in the Marcellus shale area where three regulatory committees were implemented ex-post.[168]

Academic scholars who have studied the perception of hydraulic fracturing in the North of England have raised two main critiques of this approach. Firstly, it takes scientific issues out of the public debate since there is no debate on the use of a technology but on its impacts. Secondly, it does not prevent environmental harm from happening since risks are taken then assessed instead of evaluated then taken as it would be the case with a precautionary approach to scientific debates.

The relevance and reliability of risk assessments in hydraulic fracturing communities has also been debated amongst environmental groups, health scientists, and industry leaders. A study has epitomized this point: the participants to regulatory committees of the Marcellus shale have, for a majority, raised concerns about public health although nobody in these regulatory committees had expertise in public health. That highlights a possible underestimation of public health risks due to hydraulic fracturing. Moreover, more than a quarter of the participants raised concerns about the neutrality of the regulatory committees given the important weigh of the hydraulic fracturing industry.[168] The risks, to some like the participants of the Marcellus Shale regulatory committees, are overplayed and the current research is insufficient in showing the link between hydraulic fracturing and adverse health effects, while to others like local environmental groups the risks are obvious and risk assessment is underfunded.[146]

Precaution-based approach -

The second approach relies on the precautionary principle and the principal of preventive and corrective action of environmental hazards, using the best available techniques with an acceptable economic cost to insure the protection, the valuation, the restoration, management of spaces, resources and natural environments, of animal and vegetal species, of ecological diversity and equilibriums.[157] The precautionary approach has led to regulations as implemented in France and Vermont, banning hydraulic fracturing.[156][169]

Such an approach is called upon by social sciences and the public as studies have shown in the North of England and Australia.[146][167] Indeed in Australia, the anthropologist who studied the use of hydraulic fracturing concluded that the risk-based approach was closing down the debate on the ethics of such a practice, therefore avoiding questions on broader concerns that merely the risks implied by hydraulic fracturing. In the North of England, levels of concerns registered in the deliberative focus groups studied were higher regarding the framing of the debate, meaning the fact that people did not have a voice in the energetic choices that were made, including the use of hydraulic fracturing. Concerns relative to risks of seismicity and health issues were also important to the public, but less than this. A reason for that is that being withdrawn the right to participate in the decision-making triggered opposition of both supporters and opponents of hydraulic fracturing.

The points made to defend such an approach often relate to climate change and the impact on the direct environment; related to public concerns on the rural landscape for instance in the UK.[146] Energetic choices indeed have an impact on climate change since greenhouse gas emissions from fossil fuels extraction such as shale gas and oil contribute to climate change. Therefore, people have in the UK raised concerns about the exploitation of these resources, not just hydraulic fracturing as a method. They would hence prefer a precaution-based approach to decide whether or not, regarding the issue of climate change, they want to exploit shale gas and oil.

Framing of the debate -

There are two main areas of interest regarding how debates on hydraulic fracturing for the exploitation of unconventional oil and gas have been conducted.

"Learning-by-doing" and the displacement of ethics -

A risk-based approach is often referred to as "learning-by-doing" by social sciences. Social sciences have raised two main critiques of this approach. Firstly, it takes scientific issues out of the public debate since there is no debate on the use of a technology but on its impacts. Secondly, it does not prevent environmental harm from happening since risks are taken then assessed instead of evaluated then taken. Public concerns are shown to be really linked to these issues of scientific approach. Indeed, the public in the North of England for instance fears “the denial of the deliberation of the values embedded in the development and application of that technology, as well as the future it is working towards” more than risks themselves. The legitimacy of the method is only questioned after its implementation, not before. This vision separates risks and impacts from the values entitled by a technology. For instance, hydraulic fracturing entitles a transitional fuel for its supporters whereas for its opponents it represents a fossil fuel exacerbating the greenhouse effect and global warming. Not asking these questions leads to seeing only the mere economic cost-benefit analysis.[146]
This is linked to a pattern of preventing non-experts from taking part in scientific-technological debates, including their ethical issues. An answer to that problem is seen to be increased public participation so as to have the public deciding which issues to address and what political and ethical norms to adopt as a society. Another public concern with the “learning-by-doing” approach is that the speed of innovation may exceed the speed of regulation and since innovation is seen as serving private interests, potentially at the expense of social good, it is a matter of public concern. Science and Technology Studies have theorized “slowing-down” and the precautionary principle as answers. The claim is that the

possibility of an issue is legitimate and should be taken into account before any action is taken.[146]

8. VARIATIONS IN RISK-ASSESSMENT OF ENVIRONMENTAL IMPACTS OF HYDRAULIC FRACTURING

Issues also exist regarding the way risk assessment is conducted and whether it reflects some interests more than others. Firstly, an issue exists about whether risk assessment authorities are able to judge the impact of hydraulic fracturing in public health. A study conducted on the advisory committees of the Marcellus Shale gas area[168] has shown that not a single member of these committees had public health expertise and that some concern existed about whether the commissions were not biased in their composition. Indeed, among 51 members of the committees, there is no evidence that a single one has any expertise in environmental public health, even after enlarging the category of experts to “include medical and health professionals who could be presumed to have some health background related to environmental health, however minimal”. This cannot be explained by the purpose of the committee since all three executive orders of the different committees mentioned environmental public health related issues. Another finding of the authors is that a quarter of the opposed comments mentioned the possibility of bias in favor of gas industries in the composition of committees. The authors conclude saying that political leaders may not want to raise public health concerns not to handicap further economic development due to hydraulic fracturing.

Secondly, the conditions to allow hydraulic fracturing are being increasingly strengthened due to the move from governmental agencies’ authority over the issue to elected officials’ authority over it. The Shale Gas Drilling Safety Review Act of 2014 issued in Maryland[170] forbids the issuance of drilling permits until a high standard “risk assessment of public health and environmental hazards relating to hydraulic fracturing activities” is conducted for at least 18 months based on the Governor’s executive order.

Institutional discourse and the public -

A qualitative study using deliberative focus groups has been conducted in the North of England,[146] where there is a big shale gas reservoir exploited by hydraulic fracturing. These group discussions reflect many concerns on the issue of the use of unconventional oil and gas. There is a concern about trust linked with a doubt on the ability or will of public authorities to work for the greater social good since private interests and profits of industrial companies are seen as corruptive powers. Alienation is also a concern since the feeling of a game rigged against the public rises due to “decision making being made on your behalf without being given the possibility to voice an opinion". Exploitation also arises since economic rationality that is seen as favoring short-termism is accused of seducing policy-makers and industry. Risk is accentuated by what is hydraulic fracturing as well as what is at stake, and "blind spots" of current knowledge as well as risk assessment analysis are accused of increasing the potentiality of negative outcomes. Uncertainty and ignorance are seen as too important in the issue of hydraulic fracturing and decisions are therefore perceived as rushed, which is why participants favored some form of precautionary approach. There is a major fear on the possible disconnection between the public’s and the authorities’ visions of what is a good choice for the good reasons. Potential conditions of acceptance thus require representation of the public, redistribution of expertise – closing the gap between representatives and citizens and between lay person and experts –, justice as fairness and social good, precaution, humility of scientific knowledge (…) and a process of deliberative appraisal and scrutiny". Two movements sum up these potential solutions: the democratization of democracy and the politicization of technology.

It also appears that media coverage and institutional responses are widely inaccurate to answer public concerns. Indeed, institutional responses to public concerns are mostly inadequate since they focus on risk assessment and giving information to the public that is considered anxious because ignorant. But public concerns are much wider and it appears that public knowledge on hydraulic fracturing is rather good.[146]

9. PUBLIC DEBATE

Politics and public policy -

The considerable opposition against hydraulic fracturing activities in local townships has led companies to adopt a variety of public relations measures to assuage fears about hydraulic fracturing, including the admitted use of "military tactics to counter drilling opponents". At a conference where public relations measures were discussed, a senior executive at Anadarko Petroleum was recorded on tape saying, "Download the US Army / Marine Corps Counterinsurgency Manual, because we are dealing with an insurgency", while referring to hydraulic fracturing opponents. Matt Pitzarella, spokesman for Range Resources also told other conference attendees that Range employed psychological warfare operations veterans. According to Pitzarella, the experience learned in the Middle East has been valuable to Range Resources in Pennsylvania, when dealing with emotionally charged township meetings and advising townships on zoning and local ordinances dealing with hydraulic fracturing.[171][172]

Police officers have at the same time recently been forced to deal with intentionally disruptive and even potentially violent opposition to oil and gas development. In March 2013, ten people were arrested[173] during an "anti-fracking protest" near New Matamoras, Ohio, after they illegally entered a development zone and latched themselves to drilling equipment. In northwest Pennsylvania, there was a drive-by shooting at a well site, in which an individual shot two rounds of a small-caliber rifle in the direction of a drilling rig, just before shouting profanities at the site and fleeing the scene.[174] And in Washington County, Pennsylvania, a contractor working on a gas pipeline found a pipe bomb that had been placed where a pipeline was to be constructed, which local authorities said would have caused a “catastrophe” had they not discovered and detonated it.[175]

Media coverage -

Josh Fox's 2010 Academy Award nominated film *Gasland* [176] became a center of opposition to hydraulic fracturing of shale. The movie presented problems with ground water contamination near well sites in Pennsylvania, Wyoming, and Colorado.[177] *Energy in Depth*, an oil and gas industry lobbying group, called the film's facts into question.[178] In response, a rebuttal of *Energy in Depth*'s claims of inaccuracy was refuted on *Gasland's* website.[179]

The Director of the Colorado Oil and Gas Conservation Commission (COGCC) offered to be interviewed as part of the film if he could review what was included from the interview in the final film but Fox declined the offer.[180] Exxon Mobil, Chevron Corporation and ConocoPhillips aired advertisements during 2011 and 2012 that claimed to describe the economic and environmental benefits of natural gas and argue that hydraulic fracturing was safe.[181]

The film *Promised Land*, starring Matt Damon, takes on hydraulic fracturing.[182] The gas industry is making plans to try to counter the film's criticisms of hydraulic fracturing with informational flyers, and Twitter and Facebook posts.[181]

On January 22, 2013 Northern Irish journalist and filmmaker Phelim McAleer released a crowdfunded[183] documentary called *FrackNation* as a response to the claims made by Fox in *Gasland*. *FrackNation* premiered on Mark Cuban's AXS TV. The premiere corresponded with the release of *Promised Land*.[184]

On April 21, 2013, Josh Fox released Gasland 2, a documentary that declares the gas industry's portrayal of natural gas as a clean and safe alternative to oil is a myth, and that hydraulically fractured wells inevitably leak over time, contaminating water and air, hurting families, and endangering the earth's climate with the potent greenhouse gas methane.

10. RESEARCH ISSUES

Typically the funding source of the research studies is a focal point of controversy. Concerns have been raised about research funded by foundations and corporations, or by environmental groups, which can at times lead to at least the appearance of unreliable studies.[185][186] Several organizations, researchers, and media outlets have reported difficulty in conducting and reporting the results of studies on hydraulic fracturing due to industry[187] and governmental pressure,[9] and expressed concern over possible censoring of environmental reports.[187][188][189] Researchers have recommended requiring disclosure of all hydraulic fracturing fluids, testing animals raised near fracturing sites, and closer monitoring of environmental samples.[190] Many believe there is a need for more research into the environmental and health effects of the technique.[191][192]

11. CONCLUSION

Studying the potential environmental impacts of drilling, specifically the use of hydraulic fracturing techniques, has proven particularly challenging because of significant unknown factors and an overall lack of agreement among scientists due in part to the poor quality and limited amount of publicly available data. The study has substantial potential to provide reliable data that can be used as a basis for energy policy in the near future. If managed appropriately, natural gas resources, and shale gas specifically, can be essential to the energy security of the U.S. and the world. Realization of the full benefit of this tremendous energy asset can only come about through resolution of controversies through effective policies and regulations. Fact-based regulations and policies based on sound science are crucial for achieving the twin objectives of shale gas resource availability and protection of human health and the environment. As concerned citizens and researchers learn more about the short-term dangers of hydraulic fracturing, the long-term horrors on the environment remain unknown.

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(Received 20 January 2016; accepted 05 February 2016)