Primer on Hydraulic Fracturing Concerning Initiatives on Energy Sustainability

Michael Holloway[1,*] and Oliver Rudd[2]

[1]*NCH Corporation, Irving, TX, USA*
[2]*Independent Consultant, TX, USA*

Received September 04, 2012; Accepted November 11, 2012

Abstract: Hydraulic fracturing (also known as fracking, fracing, and other variations) of rock deep beneath the Earth's surface to release petroleum product has become a contentious subject across the globe. This practice is not to be confused with drilling or extraction. Fracing is the process of using fluid power to fracture rock to release gas and sometimes crude oil. It is not drilling, although drilling must be done to establish a well in order to pump fluid thus fracturing rock to release product. Certain countries have actually outlawed the practice of hydraulic fracturing claiming that ground water and air pollution increase due to the practice. There is also the claim that the comfort of life is adversely affected. Legitimate concerns are always available and examples to purport a concerned view are magnified, in the authors' opinion. The intent of this paper is to provide a correct and balanced view of fracturing underground rock with fluids in order to release a product to produce energy. The concept of using water to do work is nothing new. Pumping fluid below ground in order to fracture rock to release gaseous petroleum is, however, a relatively new practice. It is done with surprising precision as well as environmental concern yet it is interesting how the public reacts to the practice in relation to other techniques used throughout the world. This paper will explore the materials used as well as the concerns most common to the practice.

1 Hydraulic Fracturing

When people say that you cannot squeeze blood out of a turnip, it means that you cannot get something from a person, especially money that they do not have. You cannot squeeze blood from a turnip but you can release trapped natural gas from rock – at least that is what is being accomplished now throughout North America. One hundred years ago no one thought it possible. Very few if any contemplated the idea. Natural gas, which is primarily methane, has been proven to

**Corresponding author*: michael.holloway@nch.com

DOI: 10.7569/JSEE.2012.629503

be an excellent fuel source. It can be safely burned to create heat to power engines, boilers in factories and homes as well as powering turbines for generating electricity. Projections on natural gas volumes trapped under ground suggest a near inexhaustible supply of this product yet with such abundance spawns controversy. A popular and economical technique relies on the gas from subterranean sources requires fracturing rock bed. This process is actually carried out naturally everyday with water or magma. Magma may flow into rock beds, superheating water to generate steam. The resulting pressure of the expanding water molecule can be so great that it can lift and separate thousands of tons of rock deep beneath the Earth's surface. This same practice can be carried out artificially (induced) using high powered pumps and various liquid compounds. This technique, combined with new horizontal directional drilling machines, has enabled the harvest and distribution of natural gas. But at what cost? Does this practice contribute to greenhouse gas? Does it create earthquakes? Does it contaminate the ground water supply? These are important ideas to consider yet, and with proper examination and logic, we are confident you will gain insight and reason in a practice fueled by profit and civil concern.

No sides are taken in the following pages. This work is not intended to be pro-industry or anti-fracturing. Namely, it aims to educate the general public on what hydraulic fracturing really is, how it is conducted and what possible harms may or may not come as a result.

1.1 Environmental Impact – Reality Vs. Myth

In today's society, it is really easy for organizations – be it the general media, political groups, local organizations, unions or religious associations – to spread their beliefs to the public and push whatever agenda or ideals they may have. These beliefs could be successfully put forward with good intentions, successfully put forth with bad intentions or, in many cases, put forward with good intentions but have a negative result. Sadly, it seems human nature dictates that the first opinion heard or the opinion heard the loudest and with the most hyperbole will be what the public comes to believe. In time, once something is believed by enough people and stated as "fact" long enough, the general public will no longer even bother looking into facts and it will become part of the fabric of beliefs in our society – for instance, a few examples of this phenomenon are: 1) you, in fact, cannot see The Great Wall of China from the moon (not even close); 2) the Sherlock Holmes character never once said "Elementary, my dear Watson"; and 3) Neil Armstrong actually said, "One small step for [a] man, one giant leap for mankind."

As far as hydraulic fracturing is concerned, the aspect given the most attention by press and most all concerned organizations is the impact it may have on the environment. The question of environmental impact through fracking is, to say the least, a very emotional topic and by far the most polarizing issue;

DOI: 10.7569/JSEE.2012.629503

however, a great deal of analysis indicates that the most significant environmental risks attributed to fracking are similar to risks long associated with all drilling operations – including groundwater contamination due to inadequate cementing and/or well construction, risks associated with trucking, leaks from tanks and piping and spills from waste handling. This all-encompassing blame has given industry all the ammunition needed to claim effects attributed to hydraulic fracturing are overstated, not based on good science, or related to processes other than hydraulic fracturing.

Due to the great ongoing controversy over alleged impacts from fracking, many public groups have become deeply suspicious of the trustworthiness and overall motives of the oil and gas industry. These suspicions are continuously intensified by two things:

1. ongoing mistrust of data and findings due, in great part, to semantics, and
2. by the industry initially refusing to disclose the chemical makeup of fracking fluids and the additives used to enhance hydraulic fracturing.

1.2 The Tower of Babel and How it Could be the Cause of Much of the Fracking Debate

Most everyone has heard the story, or has a general understanding, of the Tower of Babel from the Old Testament. In the Biblical account of this story, humanity was attempting, as a unified group, to build a tower in Mesopotamia to reach the heavens…only to have their efforts brought to a halt by one of the most effective means imaginable. The efforts of this united group of people were not thwarted by military force, or by weather, or even by sickness and injury…their efforts in this undertaking were thwarted by speech. The simple fact of this story is that building of the tower came to a halt once the unified people were confounded by speech and no longer able to communicate to work together. Now far be it for this work to compare modern day hydraulic fracturing with the construction, and subsequent stop in construction, of the Tower of Babel, but much of the confusion, name-calling and general mistrust between groups on this subject can be attributed to a difference in communication. Maybe once this communication gap is bridged more effective talks can be established between industry and concerned public – in place of wasting time on mistrust and name-calling. Hopefully, this work can help to bridge that gap.

It can be easily considered that a very large portion of negativity toward hydraulic fracturing is actually attributable to processes other than hydraulic fracturing. In the discussions between industry and the public, a great deal of this problem can boil down to an issue of semantics…the oil and gas industry has a narrow view of what fracking entails (including just those processes

DOI: 10.7569/JSEE.2012.629503

related to the actual process of fracking while on location conducting the fracking operation) while the general public is more inclined to include many more activities commonly related to fracking (water and sand trucking, product and equipment transport and storage, water disposal), under the heading of "fracking." This can cause misunderstandings and skewed data in that many of the processes included by the general public are utilized in many, if not all, drilling practices and are hard to put solely under the heading of "fracking" when in actuality they could just as easily be under the heading "completions" or "production."

As has been discussed many times in the media and will undoubtedly be discussed again and again and again *ad nauseam*, there are many proven environmental impacts caused by drilling operations and processes related to drilling. This fact can almost assuredly not be disproven by industry personnel and can be a concern by the public in their feelings on gas well completion and production activities. However, by the same token, there have been well over a million wells that have gone through the process of hydraulic fracturing, as is defined by industry, with not one reported instance of ever impacting a fresh water aquifer. With the current issue of semantics, public concerns can include many drilling processes while industry can fall back on the fact that the industry definition of fracking has never impacted fresh water in the ways commonly claimed by the media for public consumption…and the debate can rage on with both sides being right and both sides being wrong while never taking steps to come together on a common goal.

1.3 Frac Fluids and Composition

The use of hydraulic fracturing for oil and gas exploration in the US has become highly controversial with one of the greatest points of contention between the public and industry being the makeup of frac fluids and their possible impacts on public health and the environment. This has become such a hot topic with many segments of the public for two reasons:

1. if a concern exists about the pumping of fluids into any structure, then the most concern will naturally be centered on what is being pumped, and
2. a great deal of suspicion arose and were intensified when the oil and gas industry initially balked at the disclosing the chemical makeup of fluids used to enhance hydraulic fracturing.

This has become a major argument point for the concerned public because, basically, "if you have nothing to hide why would you not want to disclose it?" Take, for example, a small child walks into a room with his hands behind his back and will not show you what is there for several minutes…and then only does when

DOI: 10.7569/JSEE.2012.629503

forced. Well, even if it turns out he was holding something as harmless as a feather behind his back it will make you suspicious all the same wondering "what was he doing with that feather!"

To make this contentious subject a little clearer, this section will provide descriptions of why frac fluids are needed, what general chemicals are needed and used, relative amounts of chemicals in frac fluid composition, proppants – the different types and uses, a discussion on slickwater, and a discussion on present regulations and standards for industry disclosure of frac fluid compositions.

1.4 Uses and Needs for Frac Fluids

There are a great deal of varied chemicals used every day in oil production wells during all phases of drilling, completions and production. These chemicals can include cements used to seal the annulus to protect the pipe and surrounding formation from damage through wells exceeding the producing and stimulation requirements placed on the pipe, temperature, and even natural ground stresses. An example is corrosion inhibitors. These chemicals help pipe and connection seals remain within design specifications to prevent failures. Corrosion prevention and treating chemicals may also be necessary due to operational and field changes – even after well completion and during production.

These chemicals can be used in much the same fashion as fracturing; however, chemicals in well operation are applied in smaller quantities, at lower pressure and in a regular maintenance driven schedule during a well's life. Just like the maintenance driven chemicals utilized during operations, chemicals serve numerous necessary functions to insure successful, safe and efficient hydraulic fracturing operations. The following provides a comprehensive look at common chemical additives utilized in the current fracturing industry.

1.5 Common Fracturing Additives

First, there is no one formula for how much each of the following additives are used in a given fracturing fluid; however, the following section is intended to present a brief description of some of the most commonly used additives and a general percentage breakdown of each that has been widely reported and is, therefore, easily verified by anyone wishing to do so.

Also, each well differs in the number, type and amount of additives (please note: the term "additives" is used to include water, sand and chemicals to allow for a discussion of each under one heading) in a successful fracture treatment – "typically" between 3 and 12 additives depending on the conditions of the specific well to be fractured and characteristic of the surrounding formations. Additives utilized in hydraulic fracturing operations are intended to serve specifically engineered uses – such as biocides to control microorganism/bacterial growth, corrosion inhibitor to prevent corrosion of pipe, viscosity agents to carry

DOI: 10.7569/JSEE.2012.629503

proppant, gelling agents to improve proppant placement, friction reduction to decrease pump friction and reduce treating pressure, oxygen scavengers to also aid in corrosion prevention in metal pipes, and acids to help remove drilling mud buildup damage.

Fluids (typically water) – usually approximately 98%–99% of the total volume – used to create the fractures in the formation and to carry a propping agent (typically silica sand) which is deposited in the induced hydraulic fractures to keep them from closing up.
Hydrochloric acid (example is 15% HCl) – usually approximately 500 to 2,000 gallons per three thousand gallons of frac fluid – used to help dissolve minerals and help remove damage near the well bore by cleaning out cement around pipe perforations, and also helps initiate fissures in the rock matrix.
Corrosion inhibitor (example is ammonium bisulfate) – usually approximately 0.2%–0.5% of acid total volume, resulting in approximately 5–10 gallons – used only in instances when acid is used to prevent pipe corrosion.
Biocides (examples are sodium hypochlorite or chlorine dioxide) – usually approximately 0.005%–0.05% of the total volume – used to control bacterial growth in the water injected into the well and prevent pipe corrosion.
Friction reducers (examples are polyacrylamide based compounds) – usually approximately 0.025% of total volume – used to reduce pipe friction and pressure in the piping required to pump fluids.
Gelling agents (examples are guar gum and cellulose) – not often used – used to thicken water-based solutions and help in suspension and transport of proppants into formation.
Crosslinking agent (examples include boric acid, titanate and zirconium) – used to enhance abilities of the gelling agent to even further aid in transport of proppant material.
Breaker solution – when cross-linking additives are added, a breaker solution is commonly added in the frac stage to cause the enhanced gelling agent to break down into a simpler fluid so it can be readily removed from the wellbore without carrying back the sand/proppant material.
Oxygen scavenger (example includes ammonium bisulfate) – used to prevent corrosion of pipe by oxygen.
Iron control and stabilizing agents (examples are citric acid and acetic acid) – used to keep iron compounds in soluble form to prevent precipitation.
Surfactant – usually approximately 0.5 to 2 gallons per thousand gallons of frac fluid – is used to promote flow of the fluids used in the fracturing process.
Scale Inhibitor (example is ethylene glycol) – seldom used – used to control the precipitation of specific carbonate and/or sulfate minerals.
Proppants (examples are sand, resin coated sand or man-made ceramic particles) – usually approximately 1%–1.9% of total volume – used to hold fissures open so gas and oil can be extracted.

DOI: 10.7569/JSEE.2012.629503

Now, I am sure many of you that have seen this type of information before are now expecting to see one of those "other uses" tables telling you that fracking fluid must be safe due to the "ingredients" of fracking fluids having such everyday uses such as: scale inhibitors having the same chemicals as windshield washer fluid, friction reducers having the same chemicals as many makeup products, surfactants being basically the same as shampoo products, proppants being play sand and hydrochloric acid also being swimming pool cleaner; these may be true in the strictest sense of the word, but this type of listing can also be very misleading and insincere, in that most all chemicals can be used for many different things, but are still not something with which you necessarily want to come in contact. For example, ammonium nitrate is commonly used in agriculture as a high-nitrogen fertilizer, nitromethane is a commonly used industrial solvent and Ryder trucks are commonly used to move families and their belongings to their dream homes – while these are also three of the common "ingredients" used in the tragic April 1995 Oklahoma City bombing of the Alfred P. Murrah Federal Building, which killed 168 people. This is, of course, a comparison made for shock value, but it is meant as such to stick in your memory as how these sorts of comparisons can be manipulated and to drive home the fact that the best policy is to study upon facts when you see a comparison like this, and make an informed decision for yourself.

1.6 Typical Percentages of Commonly Used Additives

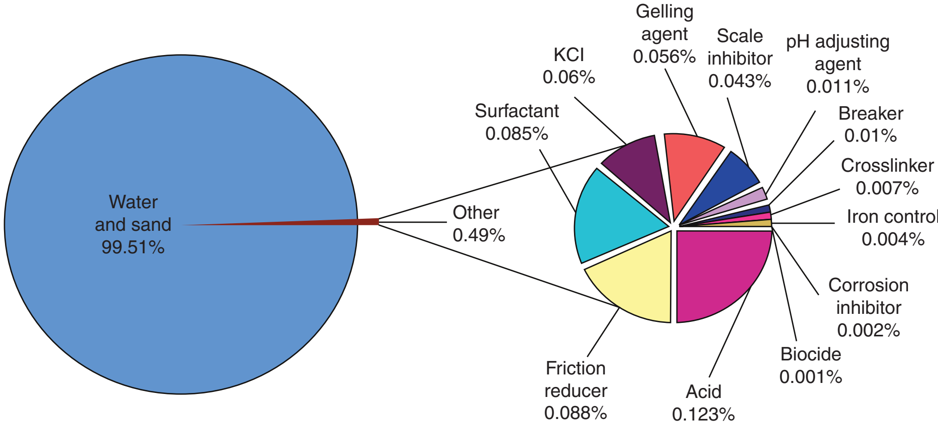
Fracturing fluids are varied to meet the specific needs of each location; however, evaluating the widely reported percentage volumes of the fracturing fluid components reveals the relatively small volume of additives that are present. Overall, the concentration of additives in most fracturing fluids is a relatively consistent 0.5% to 2%, with water and proppants making up the remaining 98% to 99.5%. Keep in mind, however, that a typical fracturing job uses upwards of five million gallons of fracturing fluid, so a small percentage amount may actually result in a great deal of chemical usage, no matter how diluted it may be.

As you can imagine, the overall composition of fracturing fluids varies among companies and the drilling location. However, as a pretty good baseline, fracturing fluids typically contain:

Approximately 90% water
Approximately 9.5% proppant materials
Approximately 0.5% chemicals – this percentage varies, but is typically between 0.5–1.0% by weight of total fluid

As described in previous sections, the chemical additives are included in fracking fluids to tailor the fluids to the requirements of the specific geological

DOI: 10.7569/JSEE.2012.629503



Graph 1 Volumetric percentages of additives in fracturing fluids from Modern Shale Gas Development in the United States.

situation. The very popular chart above taken from *Modern Shale Gas Development in the United States* demonstrates typical volumetric percentages of additives that were used for a typical hydraulic fracturing treatment of a Fayetteville Shale horizontal well (Graph 1).

1.6.1 Proppants

Proppants are pretty hard to make into anything fun, exciting or entertaining…as they are, for the most part, made up of sand or a manufactured facsimile of sand. Sure, if you want to be poetic you can refer to proppants as the only materials the operators want to remain downhole in the fractures. If you really want to think poetically, feel free to consider a proppant's life as one of making its way from origins mined within the Earth only to return to its final resting place deeper within the Earth's fractures.

As discussed earlier, proppants are simply materials (typically silica sand, resin coated silica sand, or manufactured ceramics) used to prop open the open fractures to promote flow and eventual extraction of hydrocarbons. As simple as proppants may seem, the estimated amount of proppant used in industry has grown tenfold since 2000. In some regions it is not uncommon to see upwards of four million pounds of proppant used per well and represent up to 5% of well costs. The growth in proppant usage is generally attributed to operators realizing better well completion techniques with more proppant per stage and better well pad techniques with more laterals and fracturing stages per pad.

Even considering the accelerated growth in the last decade, the evolution of proppant usage has been slow to develop over the industry lifetime as a whole.

DOI: 10.7569/JSEE.2012.629503

Consider that the first frac job was conducted in 1947, utilizing a reported approximate 20,000 pounds of uncoated frac sand, and manufactured ceramic proppant was not first used until 1983...or 36 years later. Then, approximately one year later, resin coated proppant was first introduced. As with most all technologies, as new techniques continue to develop, proppants will surely evolve further to increase effectiveness and efficiency in hydraulic fracturing.

No matter the type of proppant used, the most important characteristics for a proppant are particle size distribution, crush resistance, shape and sphericity (or roundness). Proppant materials are carefully sorted for size and sphericity to provide an efficient conduit for production of fluid from the reservoir to the wellbore. Grain size is critical because a proppant must reliably fall within certain size ranges to coordinate with downhole conditions and completion design (Figure 1).

Proppant shape and hardness qualities are also very important to the efficiency and effectiveness of a fracturing operation. A coarser proppant allows for higher flow capacity due to the larger pore spaces between grains, but it may break down or crush more readily under high closure stress, and rounder, smoother proppant shapes allow for better permeability (Figure 2).

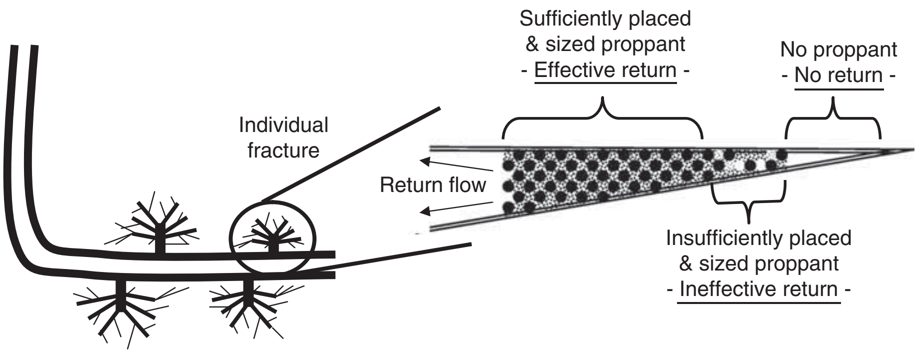


Figure 1 Proppant size and placement. Courtesy of the authors.

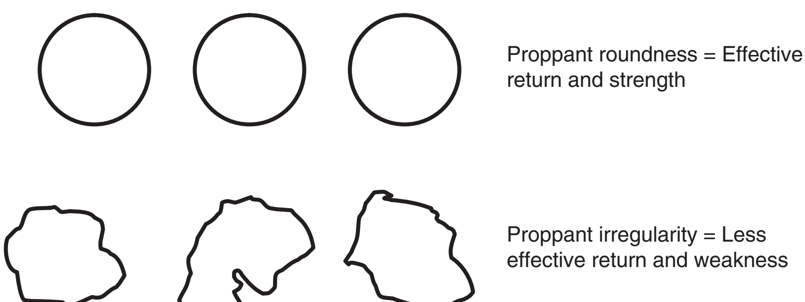


Figure 2 Proppant shape. Courtesy of the authors.

DOI: 10.7569/JSEE.2012.629503

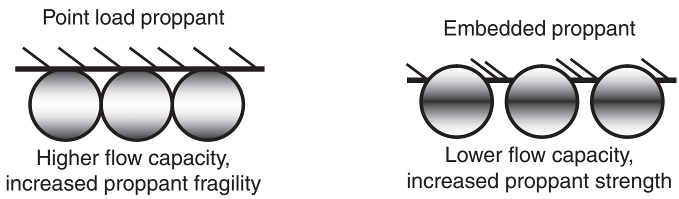


Figure 3 Proppant hardness. Courtesy of the authors.

Another important quality that must be taken into consideration is its hardness with respect to the formation. If the proppant is unable to embed in the formation, something referred to as point load occurs, which leads to higher flow capacity, but the proppant will break easier. However, if the proppant is able to embed in the formation, it is referred to as embedment, which results in the load pressure spreading out over the proppant area, increasing the breaking point but also lowering flow capacity. Embedment is also a function of particle size (Figure 3).

Even though most all proppant materials are naturally occurring, including manufactured ceramic proppants, with relatively low amounts of additional engineering necessary, the logistics in procuring and transporting proppants can be daunting. Logistical considerations include coordination of manufacturing material resources, transportation costs, and possibly a substantial monetary investment in equipment necessary for processing and material handling facilities.

1.6.2 Silica Sand

While the all-encompassing term for the material "sand" is generally used for pretty much all forms of broken down granules of minerals or rocks, to be specific falling between silt and gravel in the spectrum of sizes. There are, however, many varieties of sand in the world, each with their own unique composition and qualities. We all like to picture the white sandy beaches of vacation destinations, for example, which are made up primarily of limestone that has been broken down. Then there are also many black sands either volcanic in origin or containing magnetite. Other sands have high levels of iron in them, and so are rich and yellow in color.

The type of sand utilized for proppant materials is silica sand, which is, by far, also the most commonly used type of proppant. Silica sand, unlike many other "ingredients" of frac fluid, is more of a natural resource than an engineered product. Silica sand proppant is, in a simplistic description, made up of the most common mineral in the Earth's continental crust…quartz. Silica sand is simply quartz that over the years, through the work of time and several erosion forces, has been broken down into tiny granules. Even though silica sand is a relatively common material, silica sand used for proppant is a specifically selected and utilized

DOI: 10.7569/JSEE.2012.629503

product. Proppant quality silica sand is a direct function of both the original depositional environmental and some slight mechanical processing, if necessary. Silica sand used for proppant is chosen for its round spherical shape and commonly graded particle distribution…unlike the common sand you might find at the beach or on a playground, which often feels gritty when rubbed between the fingers.

In addition to the oil and gas industry, there is some competition between other industries for the bulk of silica sand, as industrial grade silica sand has a wide range of uses. This resource is also commonly used in the manufacture and preparations of various types of glass, in water filtration, sand blasting, as fill and as an ingredient in industrial concrete, in the metal casting industry to make cores and molds, and ironically it is also used in the creation of highly flame-resistant industrial molds and construction materials for the kilns used in the manufacture of the sintered ceramic and bauxite proppants.

Even considering all the helpful and positive uses for silica sand across several different industries, there are some possible hazards related to its use. Because of the fine grains involved in silica sand, it can present a health risk if not properly handled. Care must be taken to keep the silica sand out of the lungs during use, and all materials containing more than 0.1% of silica sand must be clearly labeled. Workplace health applications also need to be in place and enforced – failure to wear a proper respirator or mask can result in lung irritation, and prolonged exposure can cause a chronic condition known as silicosis.

Silicosis is a form of lung disease resulting from occupational exposure to silica dust over a period of years – causing a slowly progressive fibrosis of the lungs, impairment of lung function and even a heightened susceptibility to tuberculosis of the lungs. Silicosis can also progress and worsen even after someone is no longer exposed to the silica dust, causing long term effects and shortness of breath years later. Also, in the year 2000, the World Health Organization determined crystalline silica is "associated with silicosis, lung cancer and pulmonary tuberculosis" in classifying it as a Group I carcinogen "based on sufficient evidence carcinogenicity in humans and experimental animals."

1.6.3 Resin Coated Proppant

As the name suggests, and to describe in the most simplistic of terms, resin coated proppant is exactly that – silica sand coated with resin. Resin coating silica sand proppant is utilized for two main functions:

1. to spread the pressure load more uniformly to improve the crush resistance of the silica sand particles
2. to keep pieces together that were broken due to high closure stress from down hole pressure and temperature – this not only prevents broken pieces from flowing into the borehole, but also prevents these same broken pieces from returning to the surface during flowback production operation.

DOI: 10.7569/JSEE.2012.629503

Currently there are two types of resin coated proppants, *Pre-cured* and *Curable*. Pre-cured is the "original" technology in which the resin coating on the silica sand grains is fully cured prior to injection into the fractures. The newer, curable technology has often been described, and I believe very well described, as having a coating that is not completely "baked" or hardened. Curable resin coated proppants are used at a little more than half cure so that when the proppant is pumped downhole it can finish curing in the fractures with down hole pressure and temperature. The advantage to curable proppant technology is that it allows the individual proppant grains to bond together in the fracture – resulting in the grains bonding together uniformly in strength when temperature and pressure reach a appropriate levels.

1.6.4 Manufactured Ceramics Proppants

A third commonly used type of proppant is the manufactured ceramic proppant. This is a proppant generally manufactured from a type of ceramic material – typically non-metallurgic bauxite or kaolin clay. Bauxite is an aluminum ore from which most aluminum is extracted, while kaolin is one of the most common minerals, occurring in abundance from chemical weathering of rocks in hot, moist climatic soils like tropical rainforest areas.

Both bauxite and kaolin are utilized as proppants because of their superior strength characteristics which are further enhanced through a process known as sintering. The sintering process is conducted in high-temperature kilns that are used to bake the bauxite or kaolin powder after it has been made into specifically sized particles. This process decreases the water content in the bauxite and kaolin to make them more uniformly shaped for size roundness and spherical shape. The desired results of this process are that the manufactured ceramic proppants can be engineered to withstand high levels of downhole pressure (closure stress).

2 Additional Types

As more is learned through the ongoing processes and further advances are made in technology, additional types of proppants are sure to come up. One current trend is toward the usage of "waste" material – including glass, metallurgical slags, and even rock cuttings produced to the surface during oil and gas drilling. The re-use of rock cuttings from gas drilling operations is especially attractive, since not only does it re-use a common waste product in industry, but it is also utilizing sources indigenous to the locality – which will cut down wastes while also cutting down on transportation and overhead costs. However, the other possibilities are also quite attractive in that agreements can be made with landfills, metallurgical operations and glass companies to recycle and re-use their wastes in lieu of land filling.

DOI: 10.7569/JSEE.2012.629503

3 Other Most Common Objections to Drilling Operations

Now you will notice this discussion of common objections to drilling operations is a little different than other objections to drilling presented in this book for two reasons:

1. there is no attempt to separate the operations related to fracking from all other drilling operations – this is simply because most nuisances related to one operation are the same for all (for instance, additional traffic is additional traffic no matter the origination), and
2. the nuisances described in this section are not written of or discussed in a quantifiable way – in other words, this discussion is not centered on an amount, but the simple fact that it exists.

A reason for this is because a lot of data is collected for the other aspects related to fracking operations to try and prove/disprove their existence, when the nuisances discussed in this section are easily seen as in existence (just spend a few minutes along any road used for drilling operations, and this will become abundantly clear). Please keep in mind that there are many additional nuisances absorbed by those living near drilling locations or related roadways, so this listing is far from comprehensive. The following are merely what most see as the most common and are not presented in any order of magnitude. That decision has to be made by each individual – one person may be more affected by noise, while another is much more concerned with dust.

3.1 Noise

Noise conditions are usually one of the first things to change and be noticed by local landowners. An increase in noise is also one of the most continuous nuisances related to operations. Drilling and completing a well – from the pad construction to the final completion of the well – takes several weeks and utilizes many different types equipment. This additional equipment can include additional trucking, construction and drilling equipment. The noise concerns usually begin with the additional traffic brought to an area during pad construction, then continue with the noises associated with equipment and trucking required to construct a pad, only to be followed by the large amount of noise related to rig construction and operation throughout the well drilling process. Then, once the well site is completed, there may come the additional sounds of compressors used during ongoing production activities.

When you think of noise concerns related to the oil and gas industry, the first thing that commonly comes to mind is the big noisy rig or maybe the noisy traffic coming back and forth. These are, of course, very real and valid concerns; however, the thing that is quite possibly the most notable noise nuisance related to the

DOI: 10.7569/JSEE.2012.629503

oil and gas industry, due to length of time, is the compressor. For the most part, the heavy rig work and heavy truck traffic lasts approximately one to two months – while the compressor, while not as loud, can continue for a much longer amount of time (months to even years).

Gas compressors are normally the largest equipment remaining after the well development process is complete and are utilized for something called gas lift. Gas lift is used in wells that have insufficient reservoir pressure to produce efficiently on their own. The gas lift process involves injecting gas through the tubing-casing annulus to aerate the fluid to reduce its density. Following aeration of the fluid the formation pressure is then able to better lift the oil column up the wellbore. For pad sites where long term compressor use is anticipated, especially in rural communities where serenity is the norm and even the slightest ongoing noise can be heard clearly for long distances, operators have addressed compressor noise concerns with remote siting (trying to locate the compressors on the part of the pad farthest from homes), noise tampering sound walls, and directing compressors with fans away from homes. However, even with the measures presently taken to mitigate ongoing sound issues, additional work must be done and technology developed to work toward a solution.

4 Changes in Landscape and Beauty of Surroundings

Several different types of pollution are commonly mentioned in relation to the oil and gas industry – including water pollution, soil pollution, air pollution and, as presented in the previous section, noise pollution. However, one that may be overlooked to the majority of the public, but certainly not overlooked to those affected, is visual pollution. Visual pollution is an aesthetic issue, "referring to the impacts of pollution that impair one's ability to enjoy a vista or view." Now, with the possible exception of the immense number of billboards lining our nation's highways, not many things meet the definition of visual pollution as much as a drill rig.

Drill rigs utilized in most unconventional well drilling typically can range from approximately 50 feet to 100 feet in height. Couple the height of the drill rig with the ongoing movement and dust related to drilling, and it is easy to imagine how this would be bothersome to those adjacent to rig locations. One mitigation attempt for this problem would be the usage of lower height rigs. However, the undesirable trade-off for a lower height rig is the necessary extended time on location for smaller rigs.

Ironically, horizontal drilling techniques commonly related to unconventional well drilling and hydraulic fracturing locations can actually be considered a "semi-solution" to this problem. Pads used for horizontal drilling commonly include multiple laterals on one location, in which the drilling of multiple wells literally means moving the rig over as little as twenty feet from one location on the pad to the next. This allows wells to be drilled from one location without the necessity of moving the rig and drilling in several locations – which would only

DOI: 10.7569/JSEE.2012.629503

disturb that many more possible visual pollution points. This also allows for accelerated drilling time due to lessened rig movement time, a reduction in the number of necessary lease roads and drill pad locations, fewer necessary pipelines and fewer tank batteries.

5 Increased Traffic

Another nuisance commonly cited by those living in oil production areas is the drastic amount of added traffic it creates. This is not necessarily the type of traffic most of us think of when we hear the word. Traffic related to the oilfield includes all the initial traffic to bring in heavy equipment for pad construction and eventually the rig itself, followed by traffic for well completion and fracking activities (to get a taste for what this is like, consider the amount of sand used in each frac job then consider how many separate truckloads that would be), then the ongoing traffic related to hauling produced water and oil from the locations until some sort of pipeline infrastructure can be put in place.

Also, keep in mind that many of the areas affected by oil and gas operations are rural and do not, quite simply put, have the proper roadways for the larger size or amount of traffic vehicles that come with industry operations. Not only does the added traffic add additional wear and tear to the local roadways, the narrower two-lane, and sometimes even more narrow gravel roads, cause very unsafe driving conditions for the industry and local resident vehicles alike.

The answers to the traffic problems may seem obvious – do something to lessen the amount of traffic or do something to improve the roads – but finding ways to turn those answers into reality is something much more difficult than may first appear. The first, "do something to lessen the amount of traffic," would include:

1. the need to either use fewer (but larger) transport vehicles – resulting in additional hazardous conditions with the larger vehicles on the narrow rural roads, or
2. the need to install a pipeline infrastructure to transport produced water and/or oil – which comes with the obvious concerns related to pipeline installation and location.

The second, "do something to improve the roads," would depend on the type of road to be improved. Improving and widening gravel type lease and rural roads is a less daunting task than improving paved city/county roads due to ease of obtaining the proper materials and the fewer restrictions put on maintenance. However, making improvement to city and county roads would include needing to clear a wider right of way all along the road to be widened and the city/county would need to have the funds set aside for this task…which is a time consuming process.

DOI: 10.7569/JSEE.2012.629503

6 Chemicals and Products on Locations

Another common point of contention for residents in oil producing areas is on-site storage of chemicals and products. For decades, one of the biggest drivers for public concern has been the identity and amounts of chemicals stored on pad locations during all phases of the well completion and production process. This can include fuels used on location, the makeup of drilling fluids (water based, oil based or synthetic), fracking chemicals and additives stored on locations, chemicals kept on-site during ongoing production, and even the products – produced water and/or oil – stored on site as recovered from the well during operations.

The general public would be pretty surprised at how little chemical and products are stored on site during construction, drilling and frack operations. For the most part, oilfield operations have become such a streamlined and efficient operation that operators will know how much of a given chemical product will be necessary and, for the most part, make all attempts to have the chemicals arrive on location as close to when needed as possible to avoid storage. This process is beneficial to the operator in that it cuts down on the time taken up by storing chemicals only to return for them when needed, cuts down on waste from unused or outdated chemicals, cuts down on equipment needed to maneuver chemicals if you have them delivered directly to point of need, allows for more working space on the pad, and also helps avoid a great deal of logistical problems related to maneuvering equipment around storage areas.

Once production operations are in place and wells begin producing, the fluids – produced water and oil – are often stored on site in large tanks while awaiting transport off-site. Safeguards put in place to protect the environment and public from tank releases include consistent measurements by pumpers, high level shut down sensors, continued equipment observations and maintenance, and secondary containments in place around the tanks to contain any fluids that may release. Secondary containments may be constructed of properly packed and integrity tested earthen materials or up to specifically designed and manufactured metal containments with plastic liners. No matter the materials used in construction, secondary containments must be sufficiently large enough to contain all the fluids that could possibly escape the tanks plus sufficient extra space for “worst case scenario” rainfall. This amount is calculated for each region of the country based on historic rainfall data.

Even with attempts to minimize the amount of on-site storage, some chemical and product storage is unavoidable, and there are very valid concerns, including potential spills, leaks, tank or container overfill, and even the chance of traffic accidents on location or roadways leading to releases of chemicals and/or products. Release events could range from relatively small amounts from equipment leaks to possibly hundreds of barrels from tank release. Two regulatory measures in place to manage and oversee on-site chemical storage conditions are requiring Spill Prevention Countermeasure and Control (SPCC) plans and SARA reporting.

DOI: 10.7569/JSEE.2012.629503

SPCC plans are documents required by all facilities having the potential to discharge oil to navigable waters of the U.S. and meeting one or both of the following: greater than 1,320 gallons (31.4 bbls) aggregate aboveground storage in equipment, drums, tanks, totes, tanks greater than 55 gallons in size; or, greater than 42,000 gallons total underground storage capacity. Just to clarify, aggregate refers to adding up separate amounts of all storage vessels…you can have one 1,320 gallon tank or ten 132 gallon tanks and they would be equal under the SPCC requirements. Also, the "having potential to discharge oil to navigable waters of the U.S." is left up to regulatory discretion to calculate, and has come to include pretty much anywhere in the U.S. you could imagine. SPCC plans are, to keep it simple, engineer-stamped documents that must be created for all facilities meeting the above conditions that include a list of spill response procedures, an emergency notification phone list, inspection procedures and schedule, training requirements, site figures, site chemical and product storage vessel types and sizes and containment calculations to prove sufficient containment is given to contain the largest possible spill amount.

SARA reporting, or possibly better known as the federal "right to know," requires quarterly and annual reporting of chemical storage details (types of chemicals, amounts and dates of storage) for all facilities which used more than 10,000 pounds per year of the chemical exceeding the threshold quantity. This requirement means a facility storing more than 10,000 pounds of a given chemical in a year must report that chemical and amount. This program is intended as the "right to know" for emergency responders and emergency services that may respond to an emergency situation on the location so they will be able to adequately prepare for what may be stored on site. The drawback of this program as related to the oil and gas industry is that, with quarterly reporting, by the time a chemical has been reported the oilfield function requiring the chemical has normally been long complete and the chemicals are no longer on site. This basically means that once the chemical is reported as being on a location it is no longer there; however, as previously stated, oilfield operations have become such a streamlined process that if you know what has been reported for a previous location by a specified operator you can, for the most part, expect much the same chemicals and products stored at following locations. If you are really curious about all the chemicals used at a site, ask to receive a copy of the Material Safety Data Sheet of the chemicals used.

6.1 Material Safety Data Sheets (MSDS)

Anytime a company produces for sale or uses a chemical a Material Safety Data Sheet (MSDS) has to be written on the product and on file when used. Occupational Safety and Health Administration (OSHA) estimates that there are over 650,000 hazardous chemicals used daily in the United States, and that hundreds more will be added this year alone. To address the physical and health hazards of these chemicals, OSHA finalized the Hazard Communication Standard (HCS) on November

DOI: 10.7569/JSEE.2012.629503

25, 1983. The purpose of the HCS is to "ensure that the hazards of all chemicals produced or imported are evaluated, and that information concerning their hazards is transmitted to employers and employees." (29 CFR 1910.1200(a)(1)).

Employers are under obligation to use labels, MSDS, and other information to evaluate both the physical and health hazards created by the use of chemicals in their workplace, establish a program that addresses these hazards and train workers to minimize their exposure. According to an OSHA Executive Summary, "Chemical information is the foundation of workplace chemical safety programs. Without it, sound management of chemicals cannot occur. The HCS has made provision of hazard information about chemical products an accepted business practice in the United States. There is now a whole generation of employers and employees who have never worked in a situation where information about the chemicals in their workplace is not available."

Manufacturers or importers of chemicals must create or obtain a MSDS for every hazardous chemical that they produce or import (29 CFR 1910.1200(g)), and supply the appropriate one with a customer's first purchase, and any time the MSDS changes. (29 CFR 1910.1200(g)(6)(i)). Employers are not required to evaluate information on a MSDS. (29 CFR 1910.1200(d)(1)). They do, however, have a duty to study and to use it to "develop, implement and maintain... a written hazard communication program" to ensure the safety of their workers (29 CFR 1910.1200(e)(1)). To help address worker safety "at all times," OSHA requires employers to make MSDS "readily accessible during each work shift to employees when they are in their work area(s)." (29 CFR 1910.1200(g)(8)). OSHA permits electronic and other forms of access to MSDS, as long as there are "no barriers to immediate employee access in each workplace." (29 CFR 1910.1200(g)(8)).

6.1.1 Contents of an MSDS

Frac site workers as well as anyone working in an industry or market that uses chemicals will have access to an MSDS for any chemical that they may have contact with. Interestingly enough, consumer products also have MSDSs. In fact, your local hardware store has a complete file of MSDSs for all the consumer chemicals they sell and many department stores do as well. If you ever want to know the dangerous effects of a particular insecticide or cleaner you can refer to the MSDS for detailed information. Beware though; the information contained within an MSDS can be a bit foreboding. Like pharmaceuticals and over-the-counter medications, the warnings typically are meant to take into consideration any and all dangers that may happen upon exposure. Without a working knowledge of the terms and criteria put forth in the MSDS, the layperson could quickly become horrified with the prospect of using a product only to experience dizziness, dry mouth or shortness of breath (which seems to be the universal response to everything from aspirin to Zoloft®). The following is an explanation which is provided to help you interpret the information found on manufacturers' MSDSs. While the format of these data sheets varies from manufacturer to manufacturer, certain components appear on each sheet.

DOI: 10.7569/JSEE.2012.629503

6.1.2 Product Identification

The MSDS shall provide the name and address of the manufacturer and an emergency phone number where questions about toxicity and chemical hazards can be directed.

Product Name: Commercial or marketing name.
Synonym: Approved chemical name and/or synonyms.
Chemical Family: Group of chemicals with related physical and chemical properties.
Formula: Chemical formula, if applicable; i.e., the conventional scientific definition for a material.
CAS Number: Number assigned to chemicals or materials by the Chemical Abstracts Service.

6.1.3 Hazardous Ingredients of Mixtures

The MSDS shall describe the percent composition of the substance, listing chemicals present in the mixture. If it was tested as a mixture, it lists chemicals which contribute to its hazardous nature. Otherwise, it lists ingredients making up more than 1% and all carcinogens.

The OSHA permissible exposure limit (PEL), National Institute for Occupational Safety and Health (NIOSH) recommended exposure limit (REL), and/or the American Conference of Governmental Industrial Hygienists (ACGIH) threshold limit value (TLV) will also be listed, if appropriate.

The OSHA PEL is the regulated standard, while the others are recommended limits. The PEL is usually expressed in parts per million parts of air (ppm) or milligrams of dust or vapor per cubic meter of air (mg/m^3). It is usually a time weighted average (TWA) – concentration averaged over an eight hour day. Sometimes, a short term exposure limit (STEL) may be listed. The STEL is a 15 minute TWA which should not be exceeded. A ceiling limit, (c), is a concentration which may not be exceeded at any time. A skin notation means that skin exposure is significant in contributing to the overall exposure.

6.1.4 Physical Data

The MSDS shall outline the physical properties of the material. The information may be used to determine conditions for exposure. For example, one can determine whether or not a chemical will form a vapor (vapor pressure), whether this vapor will rise or fall (vapor density), and what the vapor should smell like (appearance and odor). This could help determine whether to use a fume hood or where to place ventilators. The following information is usually included:

Boiling Point: temperature at which liquid changes to vapor state.
Melting Point: temperature at which a solid begins to change to liquid.

DOI: 10.7569/JSEE.2012.629503

Vapor Pressure: a measure of how volatile a substance is and how quickly it evaporates. For comparison, the VP of water (at 20°C) is 17.5 mm Hg, Vaseline (non-volatile) is close to 0 mm Hg, and diethyl ether (very volatile) is 440 mm Hg.

Vapor Density (air = 1): weight of a gas or vapor compared to weight of an equal volume of air. Density greater than 1 indicates it is heavier than air, less than 1 indicates it is lighter than air. Vapors heavier than air can flow along just above ground, where they may pose a fire or explosion hazard.

Specific Gravity (water = 1): ratio of volume weight of material to equal volume weight of water.

Solubility in Water: percentage of material that will dissolve in water, usually at ambient temperature. Since the much of the human body is made of water, water soluble substances more readily absorb and distribute.

Appearance/Odor: color, physical state at room temperature, size of particles, consistency, odor, as compared to common substances. Odor threshold refers to the concentration required in the air before vapors are detected or recognized.

% Volatile by Volume: Percentage of a liquid or solid, by volume, that evaporates at a temperature of 70°F.

Evaporation Rate: usually expressed as a time ratio with ethyl ether = 1, unless otherwise specified.

Viscosity: internal resistance to flow exhibited by a fluid, normally measured in centistokes time or Saybolt Universal Secs.

Other Pertinent Physical Data: information such as freezing point is given, as appropriate.

6.1.5 Fire & Explosion Hazard Data

The MSDS shall include information regarding the flammability of the material and information for fighting fires involving the material.

Flashpoint: the lowest temperature at which a liquid gives off enough vapor to ignite when a source of ignition is present.

Auto-ignition Temperature: the approximate temperature at which a flammable gas-air mixture will ignite without spark or flame. Vapors and gases will spontaneously ignite at lower temperatures in oxygen than in air.

Flammable Limits: the lower explosive limit (LEL) and upper explosive limit (UEL) define the range of concentration of a gas or vapor in air at which combustion can occur. For instance, an automobile carburetor controls this mixture – too lean (not enough chemical) or too rich (not enough air, as when you flood your engine) will not ignite.

Extinguishing Media: appropriate extinguishing agent(s) for the material.

Fire-fighting Procedures: Appropriate equipment and methods are indicated for limiting hazards encountered in fire situations.

DOI: 10.7569/JSEE.2012.629503

Fire or Explosion Hazards: Hazards and/or conditions which may cause fire or explosions are defined.

6.1.6 Health Hazard Data

The MSDS shall define the medical signs and symptoms that may be encountered with normal exposure or overexposure to this material or its components. Information on the toxicity of the substance may also be presented. Results of animal studies are most often given, i.e., LD50 (mouse) = 250 mg/kg. Usually expressed in weight of chemical per kg of body weight. LD50 or lethal dose 50 is the dose of a substance which will cause the death of half the experimental animals. LC50 is the concentration of the substance in air which will cause the death of half the experimental animals. Health hazard information may also distinguish the effects of acute (short-term) and chronic (long-term) exposure.

6.1.7 Reactivity Data

The MSDS shall include information regarding the stability of the material and any special storage or use considerations.

Stability: "unstable" indicates that a chemical may decompose spontaneously under normal temperatures, pressures, and mechanical shocks. Rapid decomposition produces heat and may cause fire or explosion. Conditions to avoid are listed in this section.

Incompatibility: certain chemicals, when mixed may create hazardous conditions. Incompatible chemicals should not be stored together.

Hazardous Decomposition Products: chemical substances which may be created when the chemical decomposes or burns.

Hazardous Polymerization: rapid polymerization may produce enough heat to cause containers to explode. Conditions to avoid are listed in this section.

6.1.8 Personal Protection Information

The MSDS shall include general information about appropriate personal protective equipment for handling this material. Many times, this section of the MSDS is written for large scale use of the material. Appropriate personal protection may be determined by considering the amount of the material being used and the actual manipulations to be performed.

Eye Protection: recommendations are dependent upon the irritancy, corrosiveness, and special handling procedures.

Skin Protection: describes the particular types of protective garments and appropriate glove materials to provide personnel protection.

Respiratory Protection: appropriate respirators for conditions exceeding the recommended occupational exposure limits.

Ventilation: air flow schemes (general, local) are listed to limit hazardous

DOI: 10.7569/JSEE.2012.629503

7 Conclusion

One hundred and fifty years ago when crude oil was first being extracted, the damage done to the environment was nothing short of a nightmare. In some areas little has changed but in many instances companies take extraordinary precautions. Many years ago, we did not understand the ramifications of pollution. Today, much work is underway to address what is being understood as environmental concerns. The work that goes into preparing a fracing well site today in assuring that the chemicals used are innocuous while maintaining the physical integrity of the surrounding land is taken into consideration primarily for legal reasons as well as business concerns. If environmental laws are in place, then work shall be structured accordingly. The challenge is to enact law that makes sense according to empirical evidence. It is also vital that those using the process and chemicals as well as the public understand the technology. Where industry in general fails is when it rushes forward and only applies the letter of the law and does not push for higher requirements. Legislation is often left to the most verbal and most passionate. It is fair to say that when emotion runs high, logic wanes. If we are to utilize the gifts that the Earth has bestowed upon us then it is more than fair to assume a protective role going forward and exploring proper protocols to ensure that the environment and comfort of life remain as balanced as it was found.

Bibliography

Fjaer, E. (2008). "Mechanics of hydraulic fracturing". *Petroleum related rock mechanics*. Developments in petroleum science (2 ed.). Elsevier. p. 369. ISBN 978-0-444-50260-5. http://books.google.co.uk/books?id=l6CfasFxhzYC&pg=PA369&lpg=PA369.

Laubach, S.E.; Reed R.M., Olson J.E., Lander R.H. & Bonnell L.M. (2004). „Coevolution of crack-seal texture and fracture porosity in sedimentary rocks: cathodoluminescence observations of regional fractures". Journal of Structural Geology (Elsevier) 26 (5): 967–982. doi:10.1016/j.jsg.2003.08.019. http://www.sciencedirect.com/science/article/pii/S0191814103001858.

"Definition of *frac job*". Oilfield Glossary. Schlumberger. http://www.glossary.oilfield.slb.com/Display.cfm?Term=frac%20job.

Office of Air and Radiation U.S. Environmental Protection Agency (November 2010). "General Technical Support Document for Injection and Geologic Sequestration of Carbon Dioxide: Subparts RR and UU Greenhouse Gas Reporting Program". Office of Air and Radiation U.S. Environmental Protection Agency. http://www.epa.gov/climatechange/emissions/downloads10/Subpart-RR-UU_TSD.pdf.

Jack E. Whitten, Steven R. Courtemanche, Andrea R. Jones, Richard E. Penrod, and David B. Fogl (Division of Industrial and Medical Nuclear Safety, Office of Nuclear Material Safety and Safeguards (June 2000). "Consolidated Guidance About Materials Licenses: Program-Specific Guidance About Well Logging, Tracer, and Field Flood Study Licenses (NUREG-1556, Volume 14)". US Nuclear Regulatory Commission. http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr1556/v14/#_1_26.

DOI: 10.7569/JSEE.2012.629503

Anthony Andrews et al. (30 October 2009) (PDF). *Unconventional Gas Shales: Development, Technology, and Policy Issues*. Congressional Research Service. p. ?. http://www.fas.org/sgp/crs/misc/R40894.pdf.

Bill McKibben (8 March 2012). “Why Not Frack?”. *The New York Review of Books* 59 (4). http://www.nybooks.com/articles/archives/2012/mar/08/why-not-frack/.

David Biello (30 March 2010). “What the Frack? Natural Gas from Subterranean Shale Promises U.S. Energy Independence--With Environmental Costs”. *Scientific American*. http://www.scientificamerican.com/article.cfm?id=shale-gas-and-hydraulic-fracturing.

(PDF) Chemicals Used in Hydraulic Fracturing (Report). Committee on Energy and Commerce U.S. House of Representatives. April 18, 2011. http://democrats.energycommerce.house.gov/sites/default/files/documents/Hydraulic%20Fracturing%20Report%204.18.11.pdf

DOI: 10.7569/JSEE.2012.629503