ENRG 3310 – ENERGY AND SUSTAINABILITY

Non-Hydraulic Fracturing

Policy in Support of a Transition from Hydraulic Fracturing

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Executive Summary

The United States has experienced an energy boom over the last decade that is largely the result of hydraulic fracturing. The process involves injecting a highly pressurized fluid through a drilled well into a reservoir rock. The pressure is increased until the fluid causes fractures in the reservoir rock. These fractures provide new pathways for hydrocarbons to escape the reservoir rock and enter the well for recovery.

As evidenced by the name, hydraulic fracturing uses large amounts of water as the primary fracturing fluid, and more often than not, this water is fresh groundwater. Once a well is fractured, most of the water flows back to the surface as toxic wastewater that must be disposed of in a costly manner. The industry standard involves injecting the wastewater into deep disposal wells. However, this practice undoubtedly causes induced earthquakes that have the potential to trigger more devastating natural earthquakes. Furthermore, there is increasing concern regarding contamination of drinking water as a result of hydraulic fracturing. For these reasons, public opinion is quickly turning against hydraulic fracturing.

Fortunately, an alternative method exists—non-hydraulic fracturing. The most common techniques involve compressing gases to the point of liquefaction and injecting these at high pressures into the reservoir rock in order to induce fractures. This method avoids many of the environmental concerns, and as will be shown, is likely to be the most cost-effective method in the near future. However, the switch to this improved technology is retarded by the upfront, initial costs. Once overcome, non-hydraulic fracturing will be an affordable, safe method to ensure our energy independence. For these reasons, it is in the federal government's best interest to financially support oil and gas companies during the transition away from hydraulic fracturing and towards non-hydraulic fracturing.

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When a well is drilled into a reservoir rock containing hydrocarbons, there exists a pressure differential between the reservoir and the well. This pressure differential acts as the primary driving force, as oil and natural gas will naturally have the tendency to migrate to a lower pressure. However, oftentimes the connected poor space and permeability, that is the tiny pathways through which hydrocarbons can flow, are so small that the hydrocarbons become trapped in the reservoir and are unable to flow into the well. Hydraulic fracturing is the process of using a highly pressurized mixture of water, chemical additives, and sand, known as proppant, to cause fractures in reservoir rocks in order to create new, larger pathways through which the hydrocarbons can flow. This method allows for larger amounts of recovered oil and natural gas at a much quicker rate than non-fractured wells [1]. The process is outlined in Figure 1 below.

When a well is fractured, large amounts of the fracturing fluid mixture returns to the surface with the oil and natural gas. This mixture often contains several chemicals and proppants such as sand. Some of the water is sent to treatment facilities while the remaining is injected deep into underground wastewater wells [2].

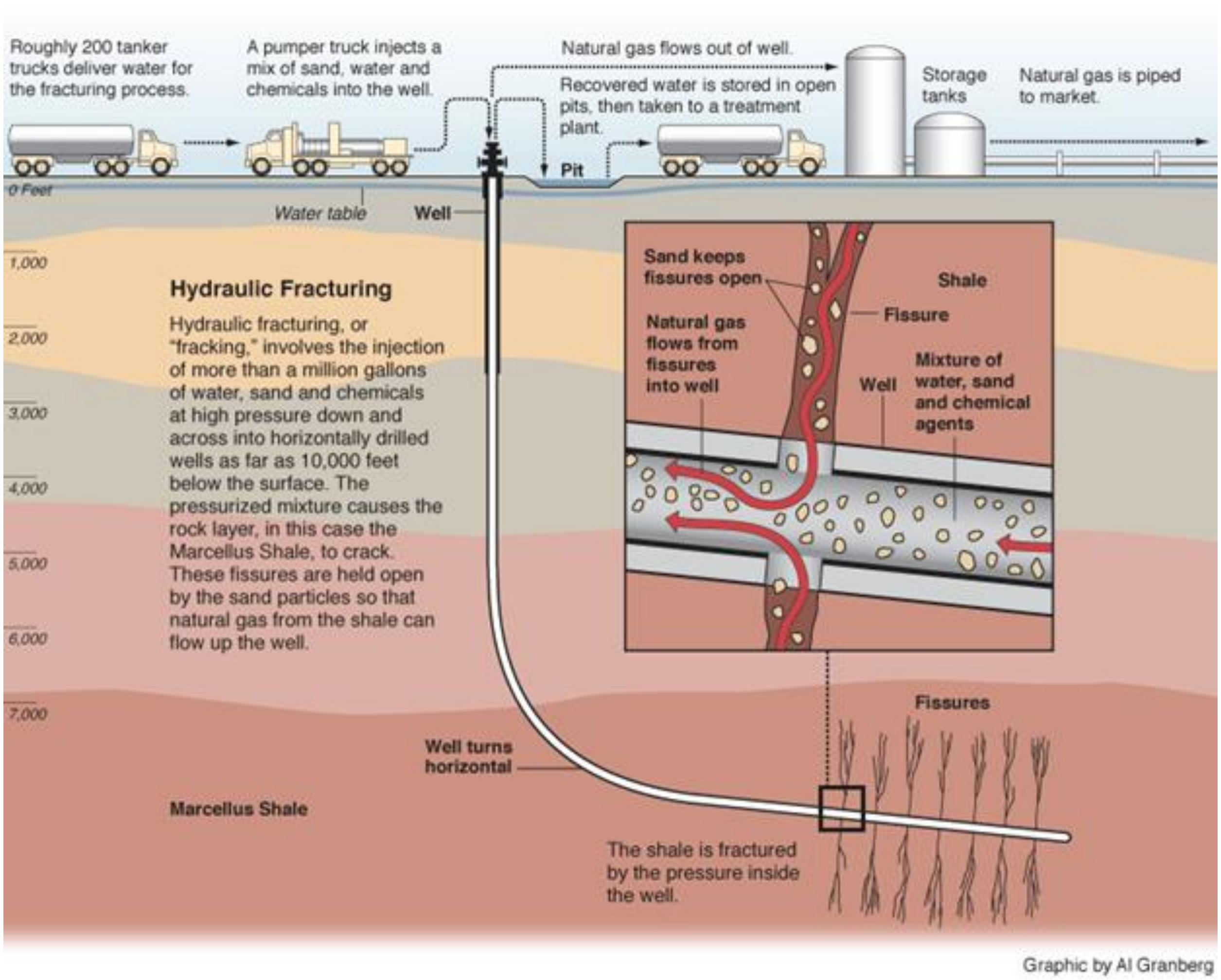

Figure 1: Hydraulic Fracturing [3]

Although the hydraulic fracturing technology was been around for decades, the practice gained immense momentum in the late 1990s and early 2000s. The surge in hydraulic fracturing has doubled American production in the last decade, placing our overall production only behind that of Saudi Arabia and Russia [4]. Details pertaining to the growth of hydraulic fracturing are provided in the following table.

Table 1: Growth of U.S. Hydraulic Fracturing [4]

Year	Number of Fractured Wells in the U.S.	Fractured Well Oil Output in the U.S. (bbls/day)
2000	23,000	102,000
2015	300,000	4,300,000

Non-Hydraulic Fracturing

The past decade has given rise to new interests in alternative methods for fracturing reservoirs. Most noteworthy are relatively new methods that involve little to no water—hence the term "non-hydraulic fracturing." Rather than using water, operators can compress gases to the point of liquefaction and use them as a fracturing fluid. One popular method that has gained momentum as of late uses compressed carbon dioxide. Once compressed, CO_2 can be injected into the reservoir at pressures sufficient enough to cause fractures in the rock. Due to its unique viscosity, it is capable of carrying sands deep into fractures in order to keep them propped open. Furthermore, due to its high volatility, the majority of the CO_2 injected into the well will return to the surface with the flow of hydrocarbons [5]. Future projections place CO_2 fracturing at the forefront of non-hydraulic fracturing and a major player in fracturing overall [6].

2008 witnessed the emergence of another non-hydraulic fracturing technology, liquefied petroleum gas (LPG) fracturing. It was debuted by Canadian operator GasFrac and uses compressed propane as its main component. The propane is compressed and cooled until it enters a jelly like state. Similarly to other methods, sand or quartz are added as proppants to support fracture openings. The LPG is then injected into the reservoir at pressures sufficient enough to fracture the reservoir rock. However, due to its low critical temperature of 213°F, any reservoir temperatures higher require the addition of butane which has a critical temperature of 350°F [7]. An inert gas such as nitrogen is often added in order to act as a gas blanket and reduce the likelihood of combustion. Furthermore, the addition of nitrogen has been shown to improve recoverability in certain situations [6].

Well Performance

In order for a new technology to replace the time-tested hydraulic fracturing process, it must be shown to perform as well or better than water as a fracturing fluid in order to meet future energy demands. It is projected that U.S. natural gas consumption will grow from 26.9 quadrillion Btu in 2013 to 30.5 quadrillion Btu in 2040 with the single largest growth in electricity generation from 8.4 quadrillion Btu to 9.6 quadrillion Btu [8]. Fortunately, non-hydraulic fracturing methods have been proven to better ensure our future energy security.

A fluid's ability to permeate throughout a reservoir rock is highly dependent on the viscosity, specific gravity, and surface tension of the fluid. Lower values in each of these categories promotes further permeation. As evidenced in the following table, LPG's stats in each of these categories drastically outperforms water. As expected, studies have shown that LPG is capable of permeating further and into smaller spaces than water. As a result, the fracture lengths created by LPG tend to be greater than those created by water [9].

Table 2: LPG v. Water [9]

Property	LPG	Water
Viscosity (centipoise at 105°F)	0.08	0.66
Specific Gravity	0.51	1.02
Surface Tension (dynes/cm)	7.6	72

Furthermore, due to water's relatively high density, hydraulic fracturing can result in a phenomenon called phase trapping. This occurs when water builds up around the wellhead and obstructs the flow of hydrocarbons into the well. This problem is even worse in reservoirs that are water-wet as most tight reservoirs are [10]. However, due to LPG's low density, surface tension, and miscibility with other hydrocarbons, it is highly unlikely that it would cause fluid blocks and phase trapping near the wellhead. If there is an accumulation of LPG near the wellhead, the pressure can be temporarily dropped in order to allow it to vaporize and exit the well [7]. An example of fracture lengths and phase trapping are offered in the following figure.

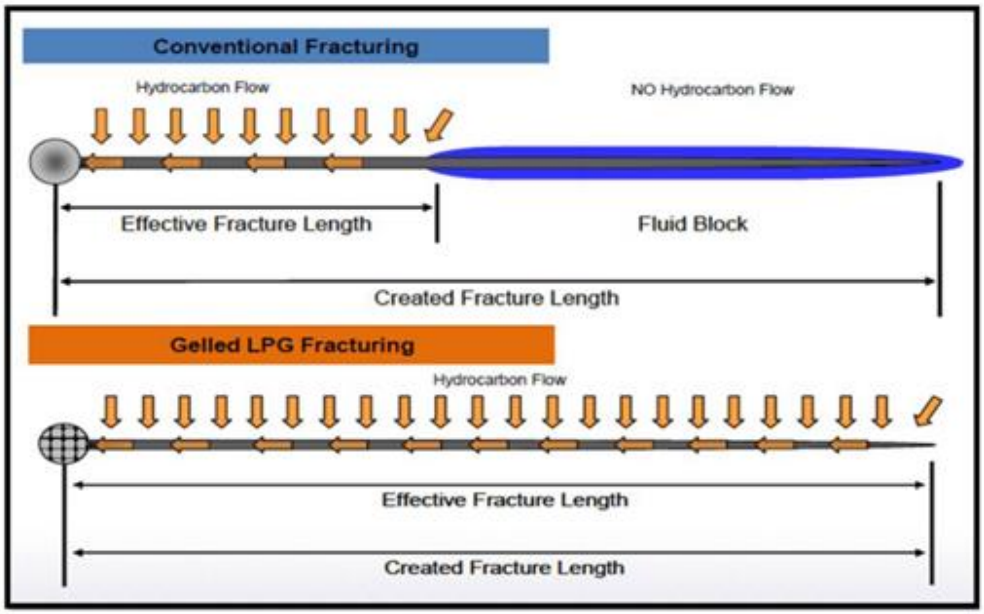

Figure 2: Fracture Lengths and Phase Trapping [10]

The improved fracture lengths witnessed with LPG require even less pressurization than that of hydraulic fracturing. This is a result of LPG's low viscosity and surface tension. As such, the chance for equipment failure due to excessive pressurization decreases with non-hydraulic fracturing. Furthermore, water has the capacity to induce clay swelling and can damage formations around the wellhead due to its ability to dissolve salts. Both of these contribute to significant flow blockages that prevent the migration of hydrocarbons into the well. LPG does not cause either of these, and is therefore a better fracturing fluid than water [9].

The performance of CO_2 as a fracturing fluid is also quite remarkable compared to water. CO_2's viscosity is even lower than that of LPG and can therefore permeate even further into reservoir rocks.

An ideal fracturing process involves using LPG to carry proppant into slightly larger pores, and then performing a second fracture job utilizing CO_2 to induce microfractures in even smaller pores in order to improve flow. Similarly to LPG, CO_2 is miscible with hydrocarbons and will therefore not likely cause phase trapping. Should a fluid block develop, pressure can be dropped in order to vaporize the CO_2 to allow escape from the wellhead. Furthermore, due to the relative simplicity of LPG and CO_2 fracture mixtures compared to the complex water mixtures, the viscosity and other characteristics of the two fracturing fluids can be easily manipulated to desired conditions [10].

Economics

Although the initial costs associated with developing a hydraulically fractured well can vary significantly, a rough estimate of $9 million to include initial set-up costs, leasing or buying of land, equipment rentals, personnel salaries, millions of gallons of water and other upfront costs is a good rule of thumb. The ongoing costs to maintain the life of the well is usually in the range of $1-3 million per year [11]. Furthermore, according to an industry expert, Senior Operations Engineer Zachary Spence with Memorial Resource Development Corp., the typical well requires 10 fracture jobs or 10 separate sessions of injecting water into the reservoir to induce fractures. Each of these hydraulic fracturing jobs costs approximately $55,000 per stage. Alternatively, non-hydraulic methods to include CO_2 and LPG fracturing may cost $90,000 to $100,000 per stage. This increased pricing is primarily due to the expensive upfront costs of equipment rental and fluid rental or purchase as this method is rarely used. However, if the industry standard switched from hydraulic to non-hydraulic methods, these per stage costs would drop significantly once companies were able to acquire the necessary equipment and fluids [12].

Mr. Spence further described the expenses associated with wastewater disposal. Operators typically pay on average $60-80,000 in the first few days to ship the wastewater to treatment facilities. After those first few days, wastewater is injected into deep wells that are often leased. Although the costs associated with each injection is less than the costs required for treatment, companies still pay millions of dollars a year on wastewater injection. Conversely, using LPG or CO_2 as a fracturing fluid requires no disposal of the fracturing fluid. Nearly all of the injected fluid returns to the surface with the reservoir fluids. This is the primary economic benefit of non-hydraulic fracturing. Due to the near complete recoverability of all fluids, the same fracturing fluid can be repeatedly reused or sold to other producers [7]. Therefore, even though the switch to non-hydraulic fracturing would require significant upfront costs in new equipment, which this paper will address in the recommendation, there is the potential for massive savings by avoiding disposal fees associated with wastewater. In the long-term, projections have demonstrated that an operator's expenses are likely to drop with a switch to non-hydraulic fracturing [13].

As described earlier, the tendency for water to cause fluid blocks or phase trapping significantly slows the flow of hydrocarbons. This is avoided by using non-hydraulic fracturing while simultaneously creating longer fracture lengths. As a result, using LPG and CO_2 will increase the productivity of wells, and the hydrocarbons will flow at a greater rate. This will minimize time sensitive costs such as leasing, equipment rentals, and personnel wages. Furthermore, due to the simplicity of LPG and CO_2 proppant mixtures, there is the potential to save on costly field experimentation often required in water proppant mixtures [10].

Environment

Health Concerns

Hydraulic fracturing requires the use of many synthetic chemicals that have the potential to present health concerns with exposure. Some common chemical additives include but are not limited to methanol, isopropanol, benzene, and ethoxylated alcohol, all of which are toxic to humans and animals [14]. Furthermore, the wastewater that returns to the surface often contains synthetic particles that were added to the fracturing fluid as well as potentially dangerous particles that were naturally found in the reservoir. It is not uncommon for wastewater to contain naturally occurring radioactive material (NORMs) that must be carefully processed and disposed of. Furthermore, the wastewater that is recovered often has extremely high levels of total dissolved solids (TDS) and is usually five times saltier than seawater. The combination of these two factors led to Pennsylvania ceasing wastewater treatment after studies found increased levels of bromide and the radioactive element radium. As a result, wastewater must be treated out of state or injected into wastewater disposal wells [13].

Unfortunately, there is growing evidence that many of these dangerous substances are polluting the environment near hydraulically fractured wells. A case study in Pavillion, Wyoming found elevated levels of dissolved methane, benzene, xylenes, and gasoline-range and diesel-range organics in the drinking water. Furthermore, there were elevated levels of chemical additives often used in hydraulic fracturing that are linked to cancer, immune system effects, changes in body weight, changes in blood chemistry, cardiotoxicity, neurotoxicity, liver and kidney toxicity, and reproductive and developmental toxicity [15]. Much of this contamination and pollution is believed to be a result of spilling at the surface. An EPA study in 2013 estimated that there is a spill for every 100 wells in Colorado and 0.4 to 12.2 spills for every 100 wells in Pennsylvania [15]. This equates to 340 confirmed leaks or spills in Colorado over a five-year period and 161 leaks or spills in Pennsylvania between 2008 and 2012. Furthermore, state records in New Mexico indicate 743 instances of oil and gas operations polluting groundwater—the source of drinking for 90 percent of the state's residents [16].

Surface spillage is not the only cause for pollution and contamination. Evidence for fluid and chemical migration from a fractured well or wastewater disposal well to aquifers and groundwater sources continues to grow. For example, wastewater injection well failure was responsible for 6.2 billion gallons of wastewater entering the Cenozoic Pecos Alluvium Aquifer near Midland, Texas. In April of 2011 in Bell Township, Pennsylvania, oil and gas company EXCO Resources knowingly pumped wastewater into a compromised well releasing wastewater into the local drinking water source. The company was eventually fined $160,000 for failing to protect the county's water source. In another example, two wastewater injection wells established in Ohio in the 1980s leaked toxic chemicals into a shallow 80 foot water well. It was stated that this wastewater injection well would be secure for at least 10,000 years, but it only took two decades for the wastewater to make the migration through fractures that were a result of induced excessive pressure [16]. All of this amounts to 2,300 confirmed wastewater injection well failures nationally in 2010 [17].

The use of LPG and CO_2 as fracturing fluids will eliminate most of these concerns. Due to the low viscosity and density of LPG and CO_2, almost all of the injected fluid returns with the formation hydrocarbons. So there is little concern regarding the presence of left over material in the reservoir. Furthermore, as all of the fracturing fluid recovered at the surface can be easily recycled or sold, there is no need for waste injection wells. Finally, due to the simple makeup of non-hydraulic fracturing fluids, should any spills occur, cleanup is easier and quicker than water-based fracturing fluids [7].

Water Scarcity

It is no secret that projected future water shortages are a major concern for governments all over the world, and the U.S. is not immune from this possibility. Forty states are expecting shortages at average conditions over the next forty years [18]. Americans currently use 44,200 million barrels of water per day, and this will increase with population and industrial growth. At the current rate, many water sources are depleted at rates greater than recovery. This is exemplified by the Colorado River and Lake Mead. The Colorado River's flow will decrease by 5-40% over the next forty years. Furthermore, its delta has shrunk from 3,000 square miles to 250 square miles. Lake Mead has witnessed water levels drop by 130 feet since 2000, and it is expected be dry by 2021 [19]. This comes at a time when the U.N. has tasked all nations with providing clean water in the adoption of the General Comment No. 15 in November 2002. Article I.1 states "The human right to water is indispensable for leading a life in human dignity. It is a prerequisite for the realization of other human rights." It also states that all individuals have a right to sufficient, safe, acceptable, and affordable water for personal and domestic use [20].

Hydraulic fracturing places a massive burden on the provision of water that will only become worse in the future and hamper efforts to provide clean, safe water. The average hydraulically fractured well typically uses around five million barrels of water throughout its lifetime. That equates to roughly 85 billion gallons of water used per year in the U.S. by oil and gas companies [17]. Furthermore, due to the contamination risks addressed above, continued hydraulic fracturing practices will jeopardize the quality of drinking water. Conversely, non-hydraulic fracturing requires no water usage, and as waste disposal wells would be become obsolete, a switch to non-hydraulic means would ensure water security for coming generations.

Seismic Activity

The explosion of hydraulic fracturing in Texas and Oklahoma has occurred simultaneously with a rapid growth in seismic activity in a region once normally unaffected by earthquakes. As described earlier, hydraulic fracturing produces large amount of wastewater, much of which is injected into deep wastewater disposal wells. These wells have been linked to increased seismic activity as a result of pressure increases near fault lines and have been labelled “induced earthquakes” [21]. For example, from 1950-2005, Oklahoma averaged 1.5 earthquakes per year of 3.0 or greater on the Richter scale. It now averages hundreds per year most often near hydraulic fracturing activity [22]. The vast majority of the induced earthquakes are relatively weak and do not pose significant risk to life and property, but they have the potential trigger much larger, natural earthquakes [22]. However, even despite their rarity, strong, induced earthquakes have occurred. Oklahoma and Texas have experienced earthquakes near the magnitude of 5.2 on the Richter scale. This is severe enough to cause structural damage to many structures [21]. The following figure plots the drastic rise in earthquakes stronger than 2.7 on the Richter scale in regions with heavy hydraulic fracturing activity. As demonstrated, a significant rise in seismic activity corresponds with the boom in hydraulic fracturing in the 21st century.

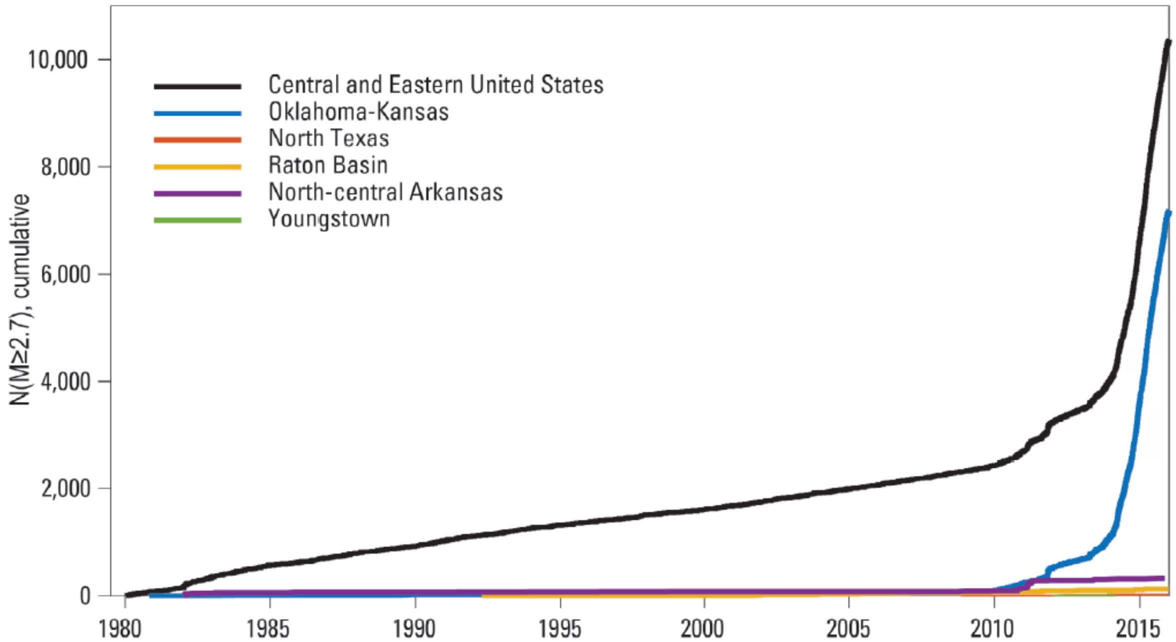

Figure 3: Growth in Seismic Activity in Heavy Hydraulic Fracturing Regions [21]

Non-hydraulic fracturing methods rid the risk of induced earthquakes secondary to wastewater injection wells. As all of the recovered fracturing fluid can easily be processed for reuse or sale, there is no need for waste injection. In fact, evidence suggests that as wastewater injection ceases, induced earthquakes in the corresponding region immediately decline in drastic fashion [21]. Furthermore, as has been described before, CO_2 and LPG behave better as fracturing fluids than water. They are able to permeate with greater ease throughout the reservoir rock due to their low viscosities and densities. As a result, the required pressure to fracture the rock is significantly less than the pressure required to fracture with water. This is also coupled with the overall better performance of CO_2 and LPG that allow for greater hydrocarbon recovery at a greater pace [9, 10]. This culminates in the reservoir rock being exposed to less pressure during the fracturing process and for a much shorter time period. As such, the chance for induced earthquakes secondary to the fracturing process drops significantly [21].

Recommendation

The switch from hydraulic to non-hydraulic fracturing will require significant upfront costs that are likely to be too costly for many operators. It is therefore necessary for the federal government to subsidize this transition. Doing so will ensure the viability of American oil and natural gas while minimizing the environmental concerns associated with hydraulic fracturing such as water contamination, water usage, and seismic activity. As these concerns dwindle and so do their required research and regulation, the federal government will be able to decrease funding on these environmental issues. As a result, over the coming decades, the federal government will likely recuperate many of the costs associated with subsidizing a switch to non-hydraulic fracturing. We propose the federal government should do the following:

1) Congress shall increase the federal gas tax by six cents.

The tax rate on gasoline has been 18.4 cents for more than 20 years. It is long overdue for an increase to adjust for modern demands and inflation. Currently, the tax grosses $35 billion per year or about $1.9 billion for every cent of the tax rate [23]. Although the exact amount required to fund the switch to non-hydraulic fracturing is beyond the scope of this paper, the revenue resulting from a five cent raise, roughly $9.5 billion, is likely to be more than enough to fund the purchasing of required trucking, piping, safety, and compression equipment for non-hydraulic fracturing.

2) Expansion of the Federal Energy Regulatory Commission

Congress shall expand the powers of the Federal Energy Regulatory Commission (FERC) to supersede state and local laws governing oil and natural gas production. The new powers invested in the FERC shall primarily focus on implementation of strict safety protocols regarding the use of LPG and other possibly combustible material as fracturing fluids. To date, thousands of wells have been fractured with LPG without a single large fire. However, in 2011, the aforementioned Canadian operator GasFrac experienced a small fire due to a propane leak. As a result, they increased the number of propane sensors per well from three to twenty and have since been accident free [13]. Continuation of this improved safety method and further research and development in this area by the FERC will ensure the safety of this practice. The expansion of the FERC shall be financed by the remaining one cent of the six cents federal gas tax increase.

3) All hydraulic fracturing processes shall be phased out within a decade.

Under direction of the president and his or her administration, congress shall legislate that due to serious concerns regarding the health of the American people, water quality, water use, and seismic activity associated with the use of hydraulic fracturing, all practices using this technology are to cease within ten years. This time frame will afford oil and natural gas operators plenty of time to adopt non-hydraulic fracturing methods.

Conclusion

Hydraulic fracturing has drastically improved the recoverability of oil and natural gas but has simultaneously introduced significant associated risks. Through water contamination secondary to spillage and migration of hydraulic fluids, the quality of local drinking water near hydraulically fractured wells is jeopardized. The impact on groundwater sources is further worsened by the massive amounts of water required to hydraulically fracture a well. Furthermore, the disposal of wastewater has been shown to cause induced earthquakes that place the property and lives of populations near hydraulic fracturing activity at risk.

Non-hydraulic fracturing has the capability to mitigate these concerns while simultaneously improving oil and natural gas recoverability to ensure future energy security. The use of little to no water in non-hydraulic fracturing processes will alleviate some of the future water scarcity projections. Furthermore, there is little likelihood of groundwater contamination and seismic activity secondary to non-hydraulic fracturing. Finally, with assistance from the federal government and the FERC, non-hydraulic fracturing will soon become the most cost-effective method for hydrocarbon extraction. It is therefore apparent that in terms of economics, energy, and environment, non-hydraulic fracturing is the clear winner and should receive the support of the federal government as outlined in this policy.

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