Hydraulic Fracturing (Fracking) Overview

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Abstract

Oil and gas wells are notably expensive: $5 million for cheap ones to $30+ million for deep, long-reach hydraulically fractured shale wells [1]. It is pricy to accumulate resources, delineate, and especially to develop such wells. Maximizing production rates and product recovery is a primary consideration when designing a development well. This is where the science of oil and gas well stimulation comes into play; greater rates and recoveries led to greater profits that are partially used to underwrite the hydrocarbon energy revolution in the United States. This paper will briefly cover the current technology and status of hydraulic fracturing of low permeability shale formation that has led to the recent re-shaping and resurgence of the oil and gas development landscape in the United States.

Introduction

Today, well stimulation is highly developed, utilizing cutting edge engineering simulation models, innovative chemistry and physics, and sophisticated economic evaluation. Stimulation techniques designed to improve fluid flow and recovery include acidizing, pumping acids into the formation

to dissolve rock; propping, small scale fracturing and propping with sand to keep the formation open; and large-scale hydraulic fracturing [2]. The Russians unsuccessfully experimented with using small yield nuclear devices to improve gas well productivity [3]. Productivity was marginally improved, but the now radioactive gas produced by the well was a significant safety hazard.

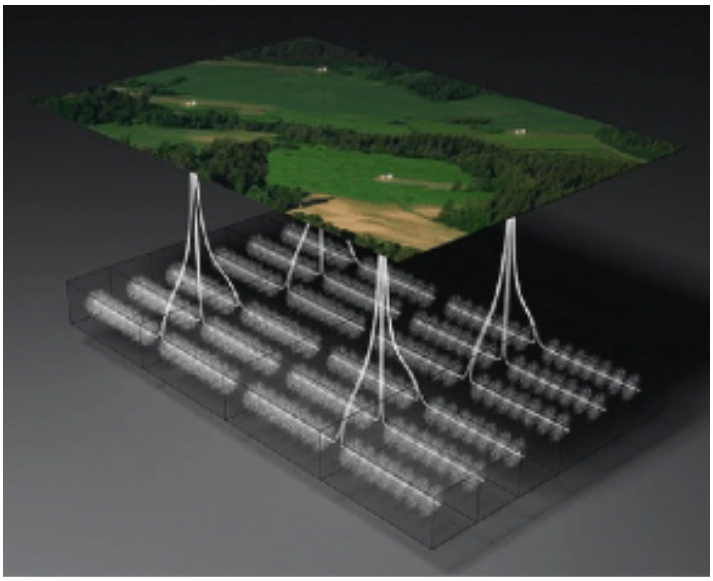


Figure 1. *A diagram depicting the subsurface layout of an area shale resource development illustrating the multi-stage frac completion design of a horizontal well geometry, The contacted rock volume is maximized while optimizing costs and surface environmental impact (surface footprints). Source: https://www.researchgate.net/figure/Shale-gas-drilling-pad-distribution-24_fig1_306510590 [4]*

Hydraulic fracturing, commonly known as fracking, is an oil well stimulation technique that combines high-pressure fluid and sand proppant injection. This is done to uniformly oriented wellbores to improve producibility, allowing for the economic extraction of oil and natural gas from low-permeability rock formations like shale. Conventional oil and gas fields are mainly produced from sandstone and limestone formations. These rocks can be highly productive with permeabilities measured in the millidarcy (mD) up to Darcy (D) levels. A Darcy level is a mechanism that is used to measure the porosity of a material. It was found that the flow rate could be directly linked to sand when looking at the characteristics and therefore determining the hydraulic conductivity. These wells often flow freely at thousands of barrels a day, utilizing natural pressure within the reservoir and permeable rocks to facilitate flow. Shale reservoirs are entirely

different, characterized by very low permeabilities, often on the microdarcy scale, and low hydrocarbon saturations per unit volume of reservoir. Familiarity with shale rock is often associated with its use in roofing materials as thin slate tiles to prevent rain and weather ingress to houses. To obtain a shale reservoir to produce any hydrocarbons at all, the permeability of the natural formation needs to be improved and stimulated, which constitutes the necessity of the fracking process. The origins of fracking date back to the late 19th century, with techniques like explosive "shooting" using nitroglycerin in oil wells. At the time, Col. Edward A.L Roberts was granted a patent for what was coined the ‘exploding torpedo. [a.

Shooters – A ‘Fracking History, American Oil & Gas Historical Society. Retrieved 12 October 2014. b. US477458A "Improvement in exploding torpedoes in artesian wells", issued 25 April 1865]. [4]

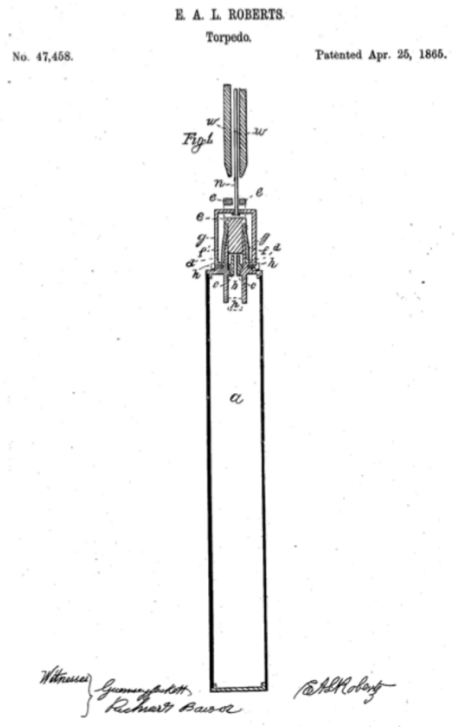


Figure 2. *"Improvement in exploding torpedoes in artesian wells," U.S. Patent 477 458, 1865 [5].*

Modern hydraulic fracturing emerged in the mid-20th century. In 1947, the first

experimental hydraulic fracturing in the Hugoton gas field, Kansas, was performed using gelled gasoline and sand. The first commercial treatments occurred in 1949, in Stephens County, Oklahoma, and Archer County, Texas, by Halliburton under license. These used oil-based fluids and sand as proppants boost production significantly upwards to 1000%. By the mid-1950s, thousands of wells were treated monthly. From the 1960s to the 1990s, fracturing expanded with larger jobs and improved fluids [6]. It remained primarily vertical-well stimulation for conventional reservoirs with particularly appropriate geology or as a last-ditch effort to eke the last drops of hydrocarbon from a field. Stimulation was expensive, and results were not reliably predictable. In the early 2000s, George P. Mitchell and others pioneered the combination of long-reach horizontal drilling with multi-stage hydraulic fracturing in shale plays (e.g., Barnett Shale in Texas) [6]. This unlocked economically viable production from tight formations. Rapid expansion followed in the Marcellus, Eagle Ford, Bakken, Permian and other shales starting around 2003. Benefits from access to these previously stranded resources include enhanced energy security, lower energy prices, air quality improvements, and CO_2 emission reductions from displacing coal. However, controversies persist around potential water contamination, high water usage, induced seismicity, wastewater management, and broader environmental and health impacts. Proper regulation, well integrity, and best practices can mitigate many risks, though data gaps remain as long term goals and aspirations. This discussion is not designed to debate over the pros and cons of utilizing technology to improve hydrocarbon recoveries. The benefits are real, and so are the concerns. The issue to be considered is to make the benefits outweigh the risks after the application of appropriate mitigation processes such as well-engineering design, regulations, and risk evaluation, among others.

Current hydraulic fracturing technology combines long-reach horizontal drilling at depths exceeding 1 mile with high-pressure fluid and proppant injection. The goal is to increase

the surface area available for fluid flow into the wellbore from very low permeable rock.

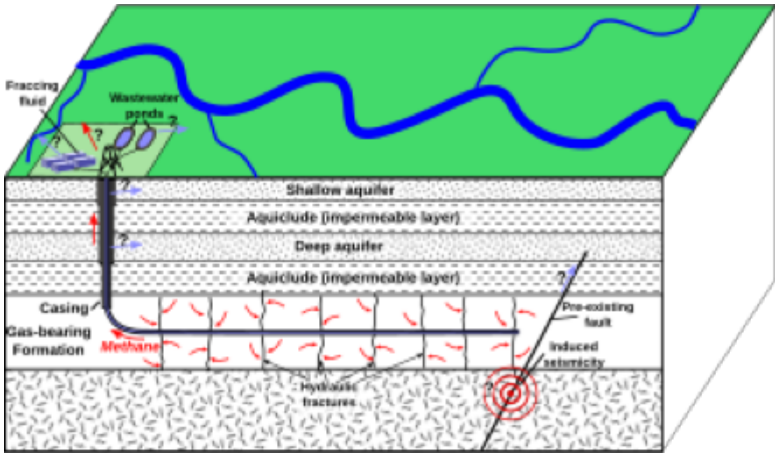


Figure 3. *Schematic depiction of hydraulic fracturing for shale gas, showing main possible environmental effects. Source: Mike Norton, 1 April 2012. Available at: https://commons.wikimedia.org/wiki/File:HydroFrac.png. [7]*

As a first step, a vertical well is drilled to the target depth before being steered horizontally through the reservoir rock for thousands of feet. Multiple concentric strings of steel casing are inserted and cemented in place for structural integrity and pressure isolation of groundwater. This initial cased wellbore is tested for pressure integrity and cement isolation effectiveness. Once the horizontal wellbore is drilled and cased, the horizontal section is selectively perforated and fracked in several stages. A perforating gun run into the wellbore creates small holes through the casing and cement into the target rock zone using shaped explosive charges. This provides tunnels up to 3 feet in length and about ½ inch in diameter for the initiation of the fracturing process.

The fracking of low permeability reservoir rock utilizes specialized engineered fluids which are pumped down the well at extremely high pressures and rates, enough to exceed the rock's fracture gradient. This creates a dense network of interconnected fractures in the treated rock volume. The fracture geometry is dependent on the strength of the formation, pressures, and the geomechanical properties of the rock. Fractures are designed to be contained within the productive reservoir and stimulate a consistent volume of rock usually extending a few hundred feet from the main wellbore. Fracture extent is limited by the available pump capacities (injection rate and

pressures). As the stimulated rock volume increases (fracture number and size grows), the energy available to propagate the fractures decreases and eventually is not sufficient to continue the fracturing process.

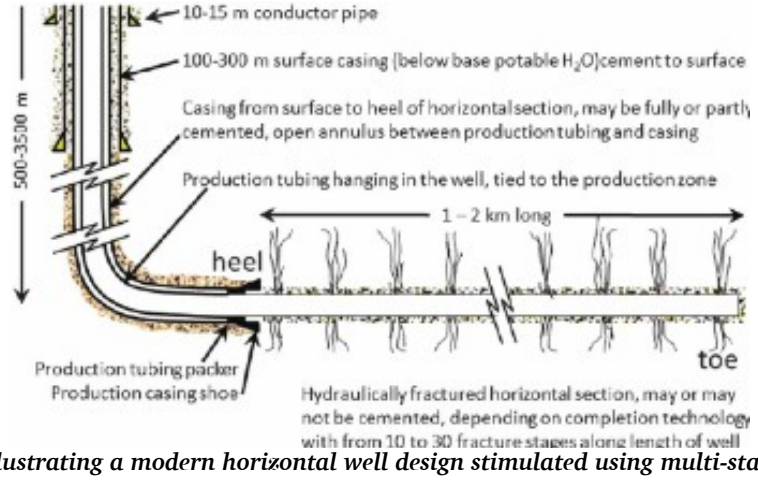


Figure 4. A diagram illustrating a modern horizontal well design stimulated using multi-stage hydraulic fracturing. Of note are the *multiple casing strings designed to isolate shallower permeable horizons and maintain wellbore stability while drilling together with the long horizontal well section and hydraulically contained production tubing. [9]*

Due to the limitations in pump capacities, a long horizontal wellbore is fracked in stages.

The first stage fracs a few hundred feet of wellbore at the 'toe' (far end) of the wellbore. This initial stage is then pressure isolated. The second stage, involved the direct stimulation of the wellbore.

This process is repeated back along the wellbore towards the 'heel'. Modern long-reach wellbores can have a versatile plethora of frac stages in a single wellbore. Multi-lateral wellbores are also utilized to increase access to reservoir volumes from a single vertical surface wellbore.

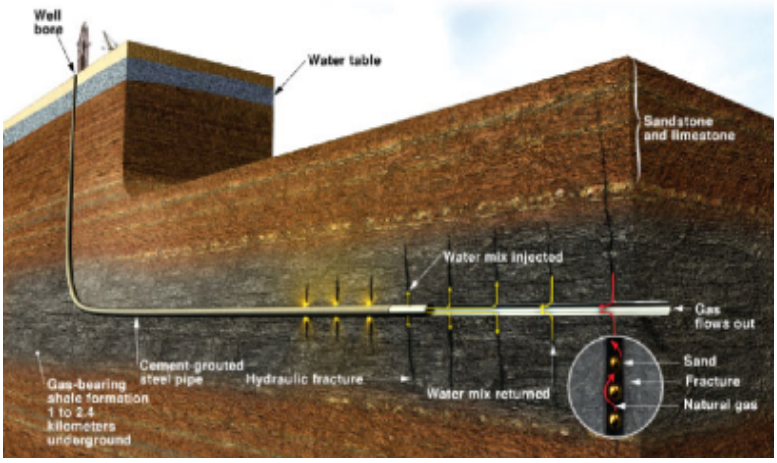


Figure 5. *Oil and gas production in shale and other low-permeability rocks requires the hydraulic stimulation of vertically oriented, radial fractures that emanate from a horizontal well bore. Natural gas flows from the fractures in the shale into the pipe and to the surface. (inset) Proppants, typically sand or ceramic spheres, hold the fractures open. (Rendering by Kwei-Yu Chu; not to scale.) Adapted from K. Walter, "A closer look at the rocky underground," Sci. Technol. Rev., Lawrence Livermore National Laboratory, Livermore, CA, USA, Jul./Aug. 2014 [10].*

Within the injected fluid is suspended proppant which is usually a specific engineered sand or ceramic particles with appropriate geometry, size distribution, and mechanical properties to allow transport to the fracture and ability to maintain the fracture open when the pressures are reduced to allow fluid production into the wellbore.

The frac fluid is generally comprised of a saltwater base (85-95%) with a variation of added chemicals (~0.5-2.0%). These additives are commonly used to modify the viscosity of the fluid,

dissolve formation of rocks, reduced bacterial growth, and inhibit corrosion of the metallic well components. About 5-15% of the injected fluid is made up of suspended sand or ceramic proppants. The frac fluids are designed to swiftly degrade at reservoir temperatures and pressures into environmentally benign products.



Figure 6. *Typical surface layout of a contemporary hydraulic fracturing spread, showing water storage, frac sand storage, pumping prime-movers, associated surface plumbing, and the development wellhead. Photo courtesy of Trican Well Service Ltd. [11].*

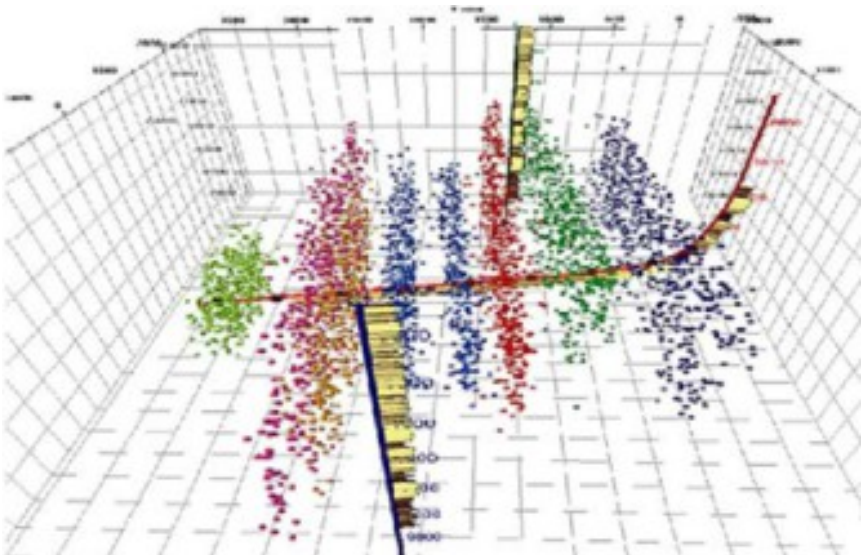


Figure 7. *Diagram showing the detected subsurface frac events from a micro-seismic survey obtained during a multi-stage frac operation. Each color represents a different frac stage while the individual dots show the location of the detected frac events. Source: Schlumberger (SLB.com)[12].*

Examples of chemicals used in frac fluids include

Acids: Hydrochloric Acid, ~15% solution: Designed to clean perforations, dissolve minerals, and initiate fractures. Used in swimming pool water quality maintenance.

Biocides: Glutaraldehyde: Engineered to kill bacteria that can produce corrosive byproducts or formations and wellbore equipment. Commonly used as a medical equipment sterilizer.

Friction and Surface Tension Modifiers

Polyacrylamide, Methanol: Reduces pumping friction and pressure losses in the system allowing more efficient application of frac energy, such as pressure and fluid rates, to the propagation of the fractures. Often paired with oils or alcohols. Also used in potable water treatments as a flocculant.

Gelling Agents

Guar Gum: Thicken fluid to carry proppant deeper into fractures. Used commonly as a food thickener.

Breakers: Ammonium Persulfate: Oxidizing chemicals to break down gels and other frac chemicals after fracturing so fluid and gas/oil can flow back. Also found in hair bleach.

Corrosion and scale inhibitors

Alcohols, organic acids, or specific amines: Designed to protect steel pipes and equipment from acid corrosion and scale buildup.

The following are foundational components of wells: Clay stabilizers (Potassium Chloride – table salt substitute), pH adjusters (Sodium Hydroxide, Sodium Carbonate – Stomach Acid Control pills), Iron Control (Citric acid – food additive, orange juice). FracFocus is a public Internet registry where operators report chemicals for individual wells. It includes trade names, purposes, and ingredients [13]. EPA and state agencies study and analyze frac fluids and their constituents prior to their use in the field. Some chemicals are hazardous, so regulations generally focus on well integrity, spill prevention and mitigation, and wastewater management to protect groundwater. These are standard industry best practices for the utilization of chemicals in industrial process where contact with the environment is likely. Prior to use, all chemicals need environmental approval with associated risk analysis, environmental impact studies and

contingency planning for unplanned releases.

Following the hydraulic fracturing process, the pressure isolation plugs in the wellbore are drilled out providing access to the entire fracked horizontal wellbore and the vertical casing.

Production tubing is run into the vertical wellbore and pressure sealed to the casing at depth adjacent to the reservoir. This production casing provides the conduit for produced fluid to be brought to the surface. The concentric space between the production tubing and the inner casing is carefully monitored during the production life of the well to ensure pressure isolation of the reservoir from the surface. Once the completion has been done, the whole system installed, the well is usually flows back to recover 40-70% the injected frac fluid. Together, with entrained vis-avis incorporation of oil and gas to clean up the well prior to long term production startup. Flowback water can be disposed of into dedicated water disposal wells into that are geologically stable high salinity shallow reservoirs). This residue is quite frequently treated and reused/recycled for subsequent frac operations.

While the many significant benefits resulting from modern frac designs are well known to industry, fracking remains divisive due to real and perceived environmental, health, and community impacts. It is the author's opinion that the real risks associated with fracking are well understood and mitigated by industry and the regulators. Many of the perceived risks making the rounds of public discussions run the range from valid to a lack of understanding. However, valid concerns remain while the technology is still at the growth stage of development. Some of the larger issues associated with fracking (though not all unique to the fracking process) are presented below:

Water Resources

High freshwater consumption (especially in arid regions) is a real concern associated with well

fracking. A large 50-stage frac job can require more than 15 million gallons of water. Industry has developed frac fluid chemistry to utilize non-potable water sourced from shallow saline aquifers, recycled frac fluid or produced water.

Risks to water resources include surface spills of fluids/chemicals, wastewater disposal, and potential groundwater contamination via poor well integrity, migration, or spills. EPA studies identified mechanisms for impacts but noted they are not widespread when best practices are followed [13]. Flowback/produced water management is a key issue. None of these risks are associated exclusively with fracking operations; they apply to all onshore oil and gas development operations, so it is an inherent industry concern.

Induced Seismicity

This issue receives significant public attention with **debatable** context or an appreciation for the magnitude or frequency of any induced seismicity. Wastewater injection into relatively shallow water disposal wells (compared to deeper shale hydrocarbon reservoirs) has caused minor earthquakes in some areas (e.g., Oklahoma). Sensitive geophysical equipment is often the only way to detect these events. Direct fracking-induced detrimental surface tremors are usually rare [15]–though they are routinely monitored using sensitive geophones to determine frac geometry and efficiency.

Air Quality, Land Use and Health

Oilfield development leading to local increases in volatile organic compounds, methane leaks, truck traffic, noise, and dust. Also, potential respiratory, neurological, or other health effects near development sites. Again, these issues are not isolated to fracking operations but are associated with the general onshore development of oil and gas resources, yet another industry problem

waiting to be solved.

The industry has responded to public concerns as well as other innovation drivers as fracking technology has evolved. Catalyzing this evolution in design is development economics, efficiency, safety, regulation, and to earn a robust 'license to operate' as responsible stewards of the resources and environment. Improvements in the industry have included optimized well design and construction, wastewater recycling, reduced chemical toxicity and environmental longevity, together with stricter regulations and oversight.

Monitoring Fracking Sites

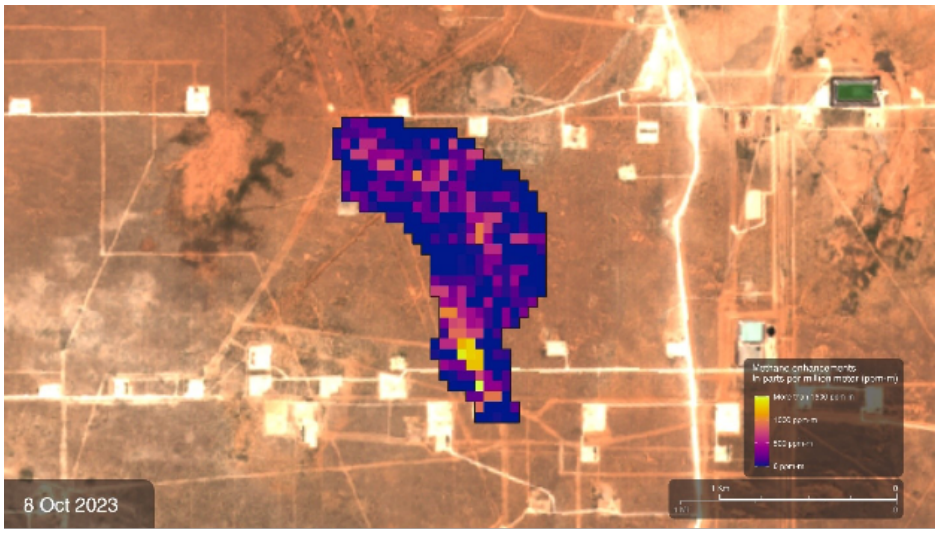


Figure 8. Satellite imagery monitoring methane emissions. Photo Credit: NASA's Scientific Visualization Studio - Navteca, *LLC./Zoey N. Armstrong, USRA/Helen-Nicole Kostis, NASA/JPL, California Institute of Technology/Andrew Thorpe, NASA/JPL, California Institute of Technology/Philip Brodrick, ADNET Systems, Inc./Laurence Schuler, ADNET Systems, Inc./Ian Jones, Public domain, via Wikimedia Commons [17]*

Tracking these large fracking sites is important and requires high accuracy. The data needed to monitor these sites comes from satellite mapping and informatics collection. Two points of concern need to be addressed through satellite monitoring. One is to keep track of the actual surface of these fracking sites and the way the land changes because of the fracking that is occurring. The second is to monitor gas emissions at these sites, which is relevant for both the safety of the sites and the safety of at-risk communities. The Texas Railroad Commission (RRC)

has recently implemented improved practices for satellite monitoring for the Permian Basin [16]. The RRC has partnered with SatSense and B3 Insight to aid in the sustaining of the Underground Injection Control program. They use SatSense's interferometric synthetic aperture radar (InSAR) measurements coupled with subsurface injection data available through B3 Insight's OilfieldH2O platform to monitor these fracking sites [18]. With this radar data, they are able to monitor the geological conditions of the basin and how those conditions are affected by the injection activity they are implementing [19]. InSAR is a remote sensing technique that can measure surface deformation, specifically including deformations over a large area with accuracy down to millimeters [20]. This is important because it also allows for the tracking of seismic risk caused by the injection activity, which is a precise matter in order to prioritize prevention of seismic activity. GHGSat is a company that uses its satellites to monitor potential leaking at the Permian Basin site [21]. Their satellites are wide-angle spectrometers that monitor methane emissions by looking for symptoms of leakage. This meant high-resolution imagery that can account for things like smoke or haze that are indicators of methane leaking. These indicators allowed for the capture of more precise imagery that was focused on these high-risk zones and then analyzed by their internal team to fully confirm these leakages [20]. Satellite imagery is important because of how it can keep track of surface and sub-surface issues that can arise from fracking.

Conclusion

Beyond these concerns, at an economic level Hydraulic fracturing is a technology that has reshaped global energy markets, offering clear economic and now dealing with potentially manageable environmental risks. The net impact depends heavily on regulatory oversight, technological improvements, and operator practices. Some considerations going forward to improve the overall impact of utilizing frac technology include strengthening well integrity design and monitoring

standards, further develop flowback and produced water treatment and recycling technology and improve industry transparency through chemical disclosure and hydromechanical testing. To best utilize the massive discovered and yet-to-be discovered shale-based hydrocarbon resources of the United States, a balanced, evidence-based policy, without blanket bans or unregulated expansion will best serve the energy needs and environmental protection requirements of the United States going forward.

Acknowledgement

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