# FRACTURE

## essays, poems, and stories on fracking in america

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# FRACTURE

# Frackenstein's Monster:

## A History of Unconventional Oil and Gas Technology

Tyler Priest

The petroleum industry has a gift for reinvention. Over the past one hundred sixty years, geologists and engineers have repeatedly revolutionized the extraction of oil and natural gas from the earth, advancing from cable tools to rotary drill bits, from doodlebugs to three-dimensional seismic, and from land rigs to deepwater platforms. Most innovations did not come as bolts from the blue. Rather, they proceeded incrementally, almost imperceptibly, until observers suddenly realized that the oil and gas industry had become a different kind of creature.

In its quest for hydrocarbons, this creature now prowls the American landscape anew, possessing the vision to see into the earth and the power to manipulate deeply embedded rock formations. It can drill down faster and farther than ever, horizontally as well as vertically, steering the drill through sharp twists and turns. It navigates by collecting real-time well data about location, pressures, and fluid properties. It sends massive volumes of sand- and chemical-laced water down into a wellbore to fracture and liberate oil and gas from rocks previously thought inaccessible.



Since 2005, the result has been a spectacular expansion of US oil and gas production, reversing decades of decline. Between 2005 and 2015, total US dry natural gas production ballooned from fifty billion cubic feet per day (bcf/d) to seventy-two bcf/d, an *increase* equivalent to the combined 2014 production of Algeria and Canada, two of the top ten gas producers in the world. Most of this rise came from hydraulically fractured shale in Pennsylvania, West Virginia, Texas, Louisiana, and Arkansas, soaring from five bcf/d in 2005 to forty bcf/d in 2015. Domestic oil production, meanwhile, climbed from 5.1 million barrels per day (b/d) in 2005 to 8.7 million b/d in 2015, an *increase* equal to the 2014 annual production from Iraq, the world's sixth largest oil producer. "Tight oil" production from fracking the Bakken formation in North Dakota and the Eagle Ford and Permian Basin regions of Texas accounted for most of this addition. The US oil and gas creature has surged to life again, making the United States the world's largest producer of oil and natural gas and reshaping the global hydrocarbon economy.

The new American oil and gas creation has generated as much fear as celebration. Concerned about harmful environmental effects and disruptive social impacts of unconventional technology, and opposed to any further development of fossil fuel resources, a vocal "anti-fracking" movement has reared up. The word, "frack," beginning with "f" and ending in "ck," has become a curse word, a "linguistic weapon in the shale-gas culture wars."[‡] For "fracktivists," the maturing oil and gas creature is not a force for progress but Frackenstein's Monster.

Similar to Mary Shelley's 1818 novel, *Frankenstein: Or, The Modern Prometheus*, hydraulic fracturing has entered the popular imagination as a cautionary tale of frightful technology unleashed upon the land. But as French sociologist and philosopher Bruno Latour observes, "Dr. Frankenstein's crime was not that he invented a creature through some combination of hubris and high technology, but rather he *abandoned the creature to itself*." Latour goes on to observe, "We confuse the monster for the creator and blame our sins against Nature on our creations." Humans create flawed technologies, not perfect ones. The moral of Shelley's story is that we should not reject our monsters but care for them just like we would our children.

Many Americans might have accepted the Frackenstein Monster if the industry had better cared for it and made it less scary. Leasing and drilling commenced in many places too fast, with too few restraints on unscrupulous operators. It proceeded without baseline studies of possible environmental impacts and the kind of transparency needed to gain public confidence. Attention to environmental controls and appropriate regulations have lagged behind advances in production. In general, the industry has been much better at addressing problems below-ground than above-ground.

Before we decide what to do about Frackenstein's Monster, we must explain the story of its creation, which has a longer and more complicated history than most people realize. Hydraulic fracturing is one aspect of the story. Equally important, but less often discussed, are the constellation of technologies that made possible deviated or horizontal drilling. In merging fracking with horizontal drilling, the industry's talented if not mad scientists created a technological marvel and changed the course of energy's future. The creature is here to stay. It is too formidable and valuable to kill. The challenge is to make it sociable.

[‡] Many industry partisans insist that "fracking" is correctly spelled "frac'ing." Both are words created by people in the industry to abbreviate "hydraulic fracturing."



## The Setting

Fracking is a uniquely American invention—for several reasons. First, the unconventional resource base is enormous. It spreads across millions of acres of easily accessible terrain. Second, US laws and policies have been particularly favorable for hydrocarbon extraction, and federal R&D lent crucial backing for the drilling innovations that commercialized fracking in unconventional formations. Finally, the competitive domestic oil and gas industry, consisting of hundreds of small-to-medium-sized companies, lightly touched by government regulation yet often struggling to survive, has had a large appetite for taking risks. Several previously unheralded "independent" firms were in the vanguard of the unconventional revolution.

The scene for this revolution was set during the Cretaceous period, around one hundred million years ago. At that time, a vast shallow sea covered the interior of the North American continent. Microorganisms proliferated in the sun-baked and nutrient-rich waters. Over millions of years, they died and settled onto the silted seafloor, creating mountains of organic material. Eventually, as the ancestral Appalachians and Rocky Mountains eroded, sediment and rock buried and compressed this material along with silt into shale formations. The heat from this compression cooked and transformed the organic material into oil and natural gas. The North American Inland Sea provided the perfect conditions for the creation of extensive shales. These are the source rocks from which oil and gas migrated into conventional sandstone reservoirs in places like Pennsylvania, where oil was first discovered in the United States, and Texas, which became the world capital of oil.

For decades, oilmen dreamed of finding a way to tap into the source rock, but they lacked the technical means of coaxing hydrocarbons from the extremely fine-grained shales. Compared to larger-sized sandstones, shales have much lower porosity (the space between the grains that house oil and gas) and permeability (the ability of a gas or fluid to flow through a porous medium). If a shale pore is the size of a marble, then a sandstone pore has the space of an auditorium. But the promise of extracting hydrocarbons from shale is that they are easy to locate. They are typically several hundred feet thick and extend evenly and contiguously across thousands of square miles. Unlike drilling into folded, faulted, and discontinuous conventional reservoirs, ninety-nine out of every one hundred wells in a known shale deposit is likely to strike petroleum. The difficulty was not in finding the resource but in extracting it.

The United States is a driller's paradise. The number of oil and gas wells that have been drilled and continue to produce in the United States dwarfs every other nation in the world. Between 1949 and 2014, there were 2.5 million oil and gas wells drilled in the United States, more than one-half the global total. This is largely due to the permissive US legal system and policy environment. Unlike most other parts of the world, ownership of mineral rights is not exclusively reserved to the state. Private ownership is widespread and long supported by federal government tax incentives, subsidies, and R&D.



Mineral rights can also be split off from surface ownership. In case of a conflict between the two estates, whoever owns the minerals is dominant. "In legal terms," writes Russell Gold, "the landowner remains the servant while the mineral owner, and the companies that lease these rights, is the master."

### Hydraulic Fracturing

The act of fracturing rock inside a well has been around almost as long as the oil and gas industry itself. In 1865, only a few years after "Colonel" Edwin L. Drake drilled the first commercial oil well in Titusville, Pennsylvania, Colonel Edward A. L. Roberts, who, unlike Drake, was an actual colonel and had served on the Union side in the Civil War, arrived in the area and introduced the idea of dropping explosives into clogged-up or non-productive wells to stimulate oil flow.

Well "shooting" became standard practice in the oil fields and progressed in diverse ways. In 1932, Dow Chemical started experimenting with hydrochloric acid to dissolve rock, a technique known as "pressure parting," which worked in limestones or carbonates, but not sandstones. In the 1930s, Ira McCullough of Los Angeles invented a method of firing bullets to perforate well casing cement. From the late 1950s and through the early 1970s, the oil industry and US Atomic Energy Commission even investigated the possibility of detonating nuclear devices underground to fracture shale. This program ceased due to exorbitant costs and alarm from citizens living near the targeted locations in southern Wyoming.

The use of fluids as a fracturing agent was the brainchild of Riley "Floyd" Farris, a star researcher at Stanolind, the exploration and production subsidiary of Indiana Standard (Amoco). In 1946, Farris and colleague Bob Fast successfully tested Farris's "hydrafrac" theory in the Hugoton natural gas field in southwestern Kansas. To reduce water's friction, along with the number of pumps needed to inject it into the well, Fast added one thousand gallons of napalm-thickened gasoline, followed by a gel breaker, to stimulate the flow of natural gas from a limestone formation. With subsequent wells in East Texas, Farris and Fast mixed in river sand to keep fractures propped open, with positive effects. The technique did not produce gushers, but it proved to be an inexpensive way to extend the life of aging conventional reservoirs. In 1948, Farris patented his hydrafrac process and issued the first license to the Halliburton Oil Well Cementing Company.

Fracking spread swiftly across the oil patch. By 1955, more than one hundred thousand wells had been fracked. Companies experimented with different kinds of fracking fluids, from gelled kerosene, to crude oil, to refined oils. Beginning in 1953, they turned to using more water, with fewer additives. Water was cheaper than crude or gasoline, so it could be pumped economically in larger volumes. The white coats in oil company research labs recommended against water, but field tests indicated otherwise. Injection rates increased with larger horsepower pumps. Improved gelling agents, such as guar crosslinked with borate, were applied. Drillers expanded the range of formations that could be fracked by adding surfactants, which are compounds that lower the surface tension between a liquid and solid, and stabilizing agents like potassium chloride, used to minimize effects on water sensitive constituents like clays. By the 1970s, the introduction of metal-based crosslinking agents further enhanced the viscosity of fracking fluids and enabled the fracturing of higher-temperature wells.



The energy crisis of the early 1970s compelled pathbreaking government research into fracking. In 1976, fears of natural gas shortages motivated Congress to authorize a federal research initiative, the Unconventional Gas Research (UGR) Program, to study technologies for recovering gas from "massive but complex unconventional gas resources, such as "tight" sandstones, Devonian-age shales, coalbed methane, and geopressured aquifers. Funded at around fifteen million dollars per year through 1995, when the program was terminated, the UGR, which became part of the Department of Energy in 1977, worked closely with the industry-sponsored Gas Research Institute (GRI), an R&D organization also created in 1976. The Eastern Gas Shale Program (EGSP) of the UGR pioneered a range of technologies that would later be commercialized in shale development, including "massive hydraulic fracturing," directionally drilled wells, downhole video cameras, nitrogen foam fracturing, and electromagnetic measurement-while-drilling sensors.

UGR researchers published many scientific papers detailing their work in the leading petroleum engineering journals. As oil and gas supplies turned from shortage to glut in the 1980s, few in the industry paid serious attention to this work. One person who did was a Houston-based independent oilman, George Mitchell, who sat on the GRI's board of directors. Mitchell had made his name and launched his company, Mitchell Energy, by discovering the Boonsville Bend gas field in Wise County, north of Fort Worth, Texas. Using Fast and Farris's hydrafracking techniques, he was able to open up the sandstone enough to yield commercial gas wells. Underneath the sandstone, however, lay the five thousand square-mile Barnett Shale, the source rock for Mitchell's gas. The work of the UGR and GRI suggested to Mitchell that this rock might provide an even greater resource.

Encouraged by federal price incentives to produce "unconventional" gas sources, Mitchell Energy attempted its first frack in the Barnett Shale in 1982. Only a trickle of gas came out the well. Not an auspicious beginning, but Mitchell, a steadfast tinkerer, was undeterred. For the next seventeen years, he persisted in drilling test wells into the Barnett, often against the advice of his investors. Finally, in 1998, an enterprising engineer with the company, Nick Steinsberger, tried a different approach. Previously, the company had fracked its shale wells with heavily gelled fluids. Engineers thought gels were necessary to crack the dense shale rocks. The gel did its job, but it also gummed up the cracks and blocked the gas from escaping. Steinsberger proposed a radical and counterintuitive idea. Why not simply use water instead of gel? It was almost as if, as Victor Frankenstein recalls, a light broke in upon Steinsberger from the darkness, "a light so brilliant and wondrous, yet so simple." At the S. H. Griffin #4 well, he pumped in a massive amount of water, with a small amount of sand and surfactants, to see if the pressure would do the trick. After a few days, gas came roaring out. This "slick-water frack" was the critical breakthrough that ignited fracking in the Barnett.

## Horizontal Drilling

Fracking did not find wider application until another innovation was combined with the slick-water technique: horizontal drilling. Steinsberger's well was a typical vertical well. It encountered only a couple hundred feet of source rock. If you could turn the well and drill along the length of the shale seam, you could frack thousands of feet of the stuff. In 2001, George Mitchell, already a billionaire in his eighties,



sold his company and its fracking discovery for 3.5 billion dollars to the Oklahoma City-based Devon Energy. When Devon successfully coupled horizontal drilling techniques with Mitchell's slick-water fracking, the race to develop unconventional oil and gas reserves began in earnest. Although often mentioned only in passing in stories about fracking, horizontal drilling is the true technological wonder.

Like fracking, the concept of horizontal drilling was nothing new to the oil patch. The first patent for using flexible shafts to rotate drill bits dates back to 1891. Although the prime application was for the dentist's chair, the patent also covered larger scale work. In 1929, the first recorded horizontal well was drilled near Texon, Texas. In subsequent decades, drillers around the world attempted non-straight line, short-radius wells but with only limited success. One problem was the inability to see where you were steering. In drilling a non-vertical well, you had to stop more frequently and take time-consuming surveys before moving on. The other problem was a lack of control over steering the drill. It could often spiral in uncharted directions. A series of interacting innovations, all of which emerged in the wake of the 1970s energy crisis, gradually solved both of these problems and established the commercial viability of horizontal drilling.

The solution to the first problem was finding a way to gather real-time downhole information without having to stop the drill. Traditionally, to collect formation data, drillers would periodically have to pull out the drill and lower a "wireline electric log" into the wellbore. Invented in the 1920s by the French well-services company Schlumberger, this instrument measured electrical (resistivity and conductivity) and acoustic properties. In doing so, it provided inferences about the characteristics of rocks and fluids in the well. Diligent work during the 1960s and 1970s led to a novel advance in well logging, called "mud-pulse telemetry," that transmitted information from the bottom of the well while allowing the drill bit to continue its path of penetration.

Conceived by J. J. Arps in 1964, mud-pulse telemetry used sensors and valves integrated into the drill assembly to convert downhole measurements into a pattern of pulses arranged in a binary code and communicated back to the drill floor. In 1978, after improvements to mud-powered turbine generators and sturdier solid-state electronics, a French-American engineering joint venture, Teleco (which later became part of Baker Hughes), under a contract with the US Department of Energy, introduced the first commercial mud-pulse tool. During the 1980s and 1990s, digital and mechanical refinements to various kinds of "measurement-while-drilling" (MWD) systems employing mud-pulse telemetry provided increasingly fast and reliable information about downhole pressures, temperatures, formation properties (electrical, acoustic, porosity, gamma ray), and wellbore trajectories. MWD improved the speed and accuracy of all kinds of drilling, but it was essential for horizontal wells.

Meanwhile, two other major innovations, along with a host of smaller ones, combined to bring greater power and maneuverability to drilling. Steerable downhole motor systems made their appearance in the late 1980s, and by the late 1990s, "rotary-steerable systems," guided by MWD, vastly increased the speed, reliability, and precision of steerable drilling. In 1982, National OilWell Varco introduced a revolutionary "Top Drive" drilling system, which removed much of the manual labor previously required to drill offshore wells and enabled the handling of longer, heavier sections of drill pipe. By the mid-1990s, portable, AC-powered Top-Drives compact enough to be installed in land-drilling derrick masts were available on the market.



Together with advanced MWD, Top Drives and rotary-steerable systems improved the practicality and economics of horizontal drilling, just as Mitchell Energy unlocked gas from the Barnett Shale.

## Reanimating the Monster

Once word leaked out about Devon's successful marrying of horizontal drilling to slick-water fracking in 2002, a leasing and drilling frenzy commenced in the Barnett, drawing in many other operators. During 2002-2003, more than 1,200 wells were drilled there, a growing percentage of them horizontals. Barnett gas production more than doubled from 0.6 bcf/d in 2002 to 1.4 bcf/d in 2006 (reaching a peak of 6.3 bcf/d in 2011).

Exhilarated by its success and content with its lease position, Devon was in no hurry to expand into other shale regions of the country. But others were, most notably, Aubrey McClendon, the brash, some would say reckless, CEO of another Oklahoma City firm, Chesapeake Energy. After Devon held a coming-out party for Wall Street analysts, writes Gold, Chesapeake "began investing billions of dollars to snap up every drillable acre it could find and kicked the shale boom into overdrive." McClendon first scooped up available acreage in the Barnett, and then in late 2005 he dispatched a battalion of landmen to lock down leases covering the Marcellus Shale in Pennsylvania. By 2008, shale gas operations had swarmed over large swaths of Appalachia. They also seemed to be moving in every direction beyond the Barnett. Southwestern Energy brought the technology to the Fayetteville Shale in Arkansas, and numerous different companies opened other shale basins, notably the Haynesville in Texas-Louisiana and the Woodford in Oklahoma.

Horizontal drilling and fracking had more surprises in store. Conventional wisdom initially held that while fracking might release small gas molecules from tiny cracks and pores in shale, much larger oil molecules would remain trapped. In late 2008, Austin-based Brigham Exploration contradicted this wisdom by producing oil from a ten thousand-foot horizontal well, the Brad Olson 100-15 #1H, from the Bakken formation in North Dakota's Williston Basin. Using "swell packers," giant rubber O-rings that swell up inside the well when exposed to oil, Brigham was able to section off the well and frack the "tight sands" of dolomite with more concentrated force in twenty different stages. Shortly after Brigham's breakthrough, EOG Resources (formerly Enron Oil & Gas), the company that introduced swell packers to North Dakota, demonstrated the efficacy of multi-stage hydraulic fracturing and horizontal drilling in the giant Eagle Ford shale formation in South Texas. From there, companies used similar technology to revive oil production from the Permian Basin of West Texas and New Mexico.

The unconventional revolution has transformed both oil and gas in the United States, with dramatic effects on the US and global economies. Like every other previous oil and gas boom, the domestic oil and gas industry lately has become a victim of its own success, as oversupply has driven down prices. Pointing to shaky, debt-driven finances and the short lifespan of wells, critics see the end of fracking on the horizon. But unconventional technology is still maturing. Companies are riding out the downturn by continuing to innovate. Microseismic monitoring, for example, has improved the understanding of fracture behavior. Multi-well pad drilling has driven down costs. Wells that are being "refracked," at a fraction of the cost



of the initial well, are showing a huge increase in oil and gas recovery. Production is increasing even as the rig count in the field is declining.

The science on the deleterious environmental effects of fracking is still emerging, but mounting evidence points to less harm to water and air than previously alleged. The chemical disclosure registry, FracFocus, founded in 2011 by the Groundwater Protection Council and the Interstate Oil and Gas Compact Commission, has dispelled many of the myths perpetuated about the chemicals used in fracking and the risks to aquifers. A 2015 Syracuse University study convincingly debunked previous research from Duke that linked the existence of methane in Pennsylvania water wells to nearby shale development. Using pre-drill baselines, a dataset a hundred times larger than the Duke studies, and a sampling of almost all the wells in the study area, not just a fraction of them, the Syracuse report established that methane levels in water wells were unrelated to their proximity to oil and gas wells. This came after a 2014 study by researchers at Echelon Consulting, Weatherford Laboratories, and the Pennsylvania Geological Survey that discovered methane in water wells in areas of northeastern Pennsylvania where there was no shale development.

Evidence also points to the relative benefits of shale gas development for fighting climate change. A 2011 Cornell University study suggesting that natural gas produced more harmful emissions than coal was discredited by other studies from Carnegie Mellon, the US Department of Energy, Worldwatch Institute, and MIT, which arrived at the opposite conclusion. A 2014 joint study between the Environmental Defense Fund and the University of Texas-Austin, the first of an ambitious series of methane studies, found that fugitive methane leaks from fracking were much lower than earlier estimates by the

US Environmental Protection Administration. A 2015 publication by air quality consultant Touche Howard made headlines by suggesting that the EDF-UT study underestimated methane releases by relying on a detector that may have been faulty. But the preponderance of evidence, so far, still supports EDF-UT's conclusion that leaks are "well below the threshold for natural gas to retain environmental and climate benefits." According to 2014 findings by the Intergovernmental Panel on Climate Change and the US National Oceanographic and Atmospheric Administration's Earth System Research Laboratory, natural gas produced by fracking has displaced coal in power generation and contributed to a welcome decrease in overall US greenhouse gas emissions.

The oil and gas industry is not hell-bent on ruining the soil, water, and air. Most operators take their environmental responsibilities seriously. Still, like Frankenstein's Monster, the Frackenstein creation has not been adequately socialized. Serious issues confront the industry. These include but are not limited to: noise and surface disruptions from twenty-four-hour drilling near residences; inexcusably poor well designs and cement casings that can lead to gas leaks; troubling disposal practices of massive volumes of water and the unnerving seismic activity associated with them; the sizable flaring of natural gas from unconventional oil wells; the destructive mining of "frac sand" proppants in the Upper Midwest; the dangerous transportation of volatile "light tight oil" by an aging rail system; and the social ills and distortions of boomtown oil and gas activity.

The domestic oil and gas industry's greatest strength, its ability to innovate and move quickly to take advantage of opportunity, is also its greatest weakness. Left unchecked, it can leave regulators and communities in the dust, sowing mistrust along the way. A 2010 interdisciplinary study by MIT, "The Future of Natural Gas," concluded that most problems caused by the industry are manageable through responsible operating practices and sensible, enforceable regulations. But there is so much money on the table and so many valuable energy resources to be claimed that efforts by states to regulate the industry or even by industry to regulate itself are too-often resisted.



We can take one of three approaches to dealing with Frackenstein's Monster. First, we can try to kill it, which some states and countries are attempting to do by banning fracking. This may temporarily solve the "problem." But fracking, like the re-animation of Frankenstein's monster, or Prometheus's gift of fire to mankind (referenced in the title of Shelley's novel), cannot be undone. Fracking is moving to other shale basins around the world and even offshore. Killing the monster is also undesirable, given the environmental advantages of generating electricity from natural gas versus coal and the heavy dependence of the United States on oil and gas for the foreseeable future, regardless of the progress made in renewable energy and conservation.

Another option would be to abandon the monster to its own devices, allowing it to storm into residential communities and the halls of legislatures, like it has in some states. This kind of *laissez-faire* approach is in nobody's interest, not even the industry's, and is not tenable for most communities encroached upon by oil and gas wells.

The last approach is to steer a middle course. We should acknowledge unconventional oil and gas as vital national assets, but we also should place conditions on developing them. Mutual understanding and compromise between the industry and its opponents are necessary to ensure that Frackenstein's Monster and everyone around it live healthy lives. Although not easy, this is really the only choice we have.

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**"One Well: Drilling the Bears Ears," Stephen Trimble**

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