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Frackonomics: Some Economics of Hydraulic Fracturing

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FRACKONOMICS: SOME ECONOMICS OF HYDRAULIC FRACTURING

Timothy Fitzgerald[†]

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INTRODUCTION

The United States has experienced an oil and gas renaissance thanks to technological innovations that have propelled unconventional resources to the forefront of energy policy discussions. Hydraulic fracturing is part of the suite of technologies that have transformed the energy industry and outlook over the past fifteen years. Commonly called “fracking,”¹ the process has been a lightning rod for public and environmental concerns about the expansion of oil and gas development. This Article introduces the economic factors behind hydraulic fracturing. These effects cut across three different scales. First is the minute scale at which microfractures in unconventional reservoirs allow large productivity increases in well investments. The second is an aggregate scale where the market supply of hydrocarbons has

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1. The phonetically appealing use of a “k” in the term has been widely adopted, though a more technical audience eschews the “k” and refers to the process as “fracing.” There are regional differences as well, with eastern regions more likely to employ the term “hydrofracturing” and variants thereof. In general, these are linguistic differences that do not pertain to technical differences between techniques, which are discussed further below. In full recognition of the signal that it entails, I adopt the more common phonetic form.

changed due to application of the new technology, with implications for global environmental issues. The third and final scale is a human scale, as tradeoffs between additional wells and environmental impacts are considered.

Oil and natural gas are formed in geologic time as organic matter is transformed by heat and pressure. Geologic strata where these transformations take place are referred to as “source rocks.” Over time, oil and gas may migrate out of the source rock and into other formations where they are trapped. Those formations are conventional reservoirs. Many times oil and gas are found together, although deposits of only oil or gas occur as well. Exploratory efforts have discovered new conventional reservoirs over time, but production depletes the known reserves. In the course of seeking productive conventional reservoirs, many source rock formations have been located. These rock formations include shales, relatively impermeable sandstones, and coal beds. Depletion, higher prices, and technological advances in exploration and production have made the unconventional resources in source rocks more attractive. Hydraulic fracturing is an essential element of the suite of technological advances that has incorporated unconventional resources into U.S. energy supply.²

Hydraulic fracturing has been hailed as a new technology, but the process used today is a distillation of advances made over several decades. Complementary technologies have contributed to the reserve additions and market effects often attributed solely to fracking. Hydraulic fracturing has been used for almost seventy years,³ though considerable research effort into the mechanics of fractures and the technicalities of how to improve production from fractured reservoirs has been made in the intervening years. The recent propagation of fracking is widely traced to 1998, when a long period of technical experimentation came to fruition in the Barnett Shale in Texas.⁴ Similar experimentation has occurred in other areas and formations as well.⁵

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2. See Howard Rogers, *Shale Gas—The Unfolding Story*, 27 OXFORD REV. ECON. POL’Y 117, 123–25 (2011) (explaining that recent advancements in hydraulic fracturing have resulted in dramatic growth in unconventional gas production).
 3. During the 1940s, Pan American Petroleum Corporation experimented with increasing well productivity through fracturing. Halliburton first commercialized the process in early 1949 under an exclusive license from Pan American that lasted until 1953. Although no commercial fracking jobs were conducted in 1949, jobs were performed at a rate of 4,500 per month by 1955. AM. PETROLEUM INST., HISTORY OF PETROLEUM ENGINEERING 600–02 (1961).
 4. DANIEL YERGIN, THE QUEST: ENERGY, SECURITY, AND THE REMAKING OF THE MODERN WORLD 327–29 (2011).
 5. See Scott R. Reeves et al., *Technology, Efficiencies Keys to Resource Expansion*, OIL & GAS J., Oct. 1, 2007, at 46, 46–47 (noting the oil and

But fracking is only part of the innovation. Unconventional resources are unlocked by a combination of technologies. The gains from directional drilling and advanced seismography add to the gains from stimulating reservoirs by fracturing.⁶ Fracking is often mischaracterized as a drilling technology. In fact, the process does not begin until *after* the wellbore is drilled. But many wells would not be drilled at all if they could not be fractured—the productivity of a well depends on all of the technical attributes. Although the combination of horizontal drilling and fracking has been especially valuable in shale reservoirs, the two need not be used together. Fracture stimulation is used in reservoirs with vertical wells, such as the Jonah gas field in Wyoming, and horizontal wellbores are used without fracturing, such as for SAG-D recovery of oil sands in Alberta.

I. HYDRAULIC FRACTURING

A nontechnical description of hydraulic fracturing helps explain the source of productivity gains.⁷ The fracking process always begins after a wellbore is drilled but usually before the well is completed and production begins. The basic idea is to inject a fluid solvent into the target formation at sufficient pressure to crack the rocks. Large pumps on the surface generate this pressure. The solvent exerts the pressure on the formation rocks and carries material (usually sand) down into the fractures that are created. When pumped into the fissures, the sand props the fractures open and keeps them open. Thus, the sand is referred to as the “proppant.” Several different sizes of sand are often used.⁸ Smaller-diameter material is injected first and pushed further from the wellbore to hold the smallest part of the fracture, with larger-diameter material filling in behind. In reservoirs

gas industry’s strong investment in recovery research and development during the late 1980s and early 1990s that yielded returns in later years).

6. Horizontal drilling is another technology that has been known for many years but recently has been increasingly utilized to boost resource production. In 1891, John Smalley Campbell obtained the first horizontal drilling patent, intended primarily for dental use but acknowledging applications for “heavy work.” U.S. Patent No. 459,152 (filed Nov. 5, 1889) (issued Sept. 8, 1891). Decades later, horizontal drilling was used to drill a Texas oil well completed in 1929. U.S. ENERGY INFO. ADMIN., DRILLING SIDEWAYS—A REVIEW OF HORIZONTAL WELL TECHNOLOGY AND ITS DOMESTIC APPLICATION 7 (1993).
7. The technically inclined reader will enjoy the detail in STANDARD HANDBOOK OF PETROLEUM AND NATURAL GAS ENGINEERING (William C. Lyons & Gary J. Plisga eds., 2d ed. 2005).
8. Increased demand for specialized sand has increased prices and triggered a supply response in the form of sandstone mining. This industry has been concentrated in the Upper Midwest, but other regions such as Montana have explored the possibility of producing natural proppant locally.

with very high pressures, sand is not strong enough to hold the fractures open, and more durable synthetic proppants can be used instead.⁹ Once the fracture is propped, hydrocarbons flow out of the surrounding rock and into the wellbore.

Four technical innovations differentiate contemporary fracking from its predecessors. First, substantially larger volumes of fluid and proppant are injected: sometimes high-volume fracturing involves injecting millions of gallons of fluid and thousands of tons of proppant.¹⁰ Larger volumes then require larger pumps on the surface. Second, two different types of fracturing jobs—water fracks and gel fracks—have been combined to form “slickwater” fracks. This combination employs the advantage of gel, which carries large amounts of proppant to enhance permeability, as well as the advantage of water, which creates more and cleaner fractures.¹¹ Third, multistage jobs are an important improvement over earlier open-hole jobs.¹² The ability to isolate sections of the wellbore leverages additional horsepower and gives more control over the process. Fourth, considerable effort has gone into optimizing the chemical additives in the injected fluid. Different additives give the fluid properties that may help it carry more material down the hole, or that may enhance production after the stimulation activity is complete. Fracturing “recipes” vary substantially between formations

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9. Synthetic proppants are generally much more expensive than natural materials, so synthetics are only used in cases where natural proppants are inadequate. While sand costs about \$0.05–\$0.10 per pound, synthetic proppants typically cost \$0.40–\$0.50 per pound.
 10. ANN DAVIS VAUGHAN & DAVID PURSELL, *FRAC ATTACK: RISKS, HYPE, AND FINANCIAL REALITY OF HYDRAULIC FRACTURING IN THE SHALE PLAYS* 12–13 (2010). A recent well in Louisiana’s Haynesville Shale might require four million gallons of water and four million pounds of proppant, while the nearby Cotton Valley formation was fractured during the mid-1980s using half as much water and much less proppant. *Id.* at 13. The Cotton Valley formation has recently been reentered, using more modern techniques, with good results. The Cotton Valley wells are still considerably cheaper than the nearby Haynesville wells in part because vertical wells are cheaper to drill than horizontal wells.
 11. *See, e.g.*, DENNIS DEGNER, *RANGE RESOURCES, HYDRAULIC FRACTURING FLUID CONSIDERATIONS IN MARCELLUS SHALE COMPLETIONS* 3–5 (2011) (discussing the benefits of “slickwater” hydraulic fracturing).
 12. An excellent description of the evolution of fracking practices in the Bakken Shale is available at *Completion Technologies*, ENERGY & ENVTL. RES. CTR., <http://www.undeerc.org/bakken/completiontechnologies.aspx> (last visited Mar. 8, 2013). While open-hole completions are “relatively quick and inexpensive,” they “provide[] little control over fracture initiation and propagation.” *Id.* More recent trends favor multistage jobs “because of [their] high degree of fracture control and long-term success rate.” *Id.*

and different firms.¹³ The characteristics of the reservoir dictate the type of fracturing that is required.

The reality of fracturing is not as simple as it sounds, in large part because the action occurs far underground where monitoring is difficult. Even with the aid of microseismic monitoring, engineers rarely know the exact geometry of fractures.¹⁴ Fractures do not necessarily propagate regularly in the deep subsurface where a complex lattice of preexisting faults and fissures can enhance or inhibit the conductivity of artificial fractures. Adding the dimension of time, the fracture morphology becomes even more tortuous; fractures can change over time. The exact topography of the fractures complicates the fluid dynamics within the reservoir, which affects the transmissivity of the reservoir. This uncertainty means that engineers constantly learn by experimentation. By studying well logs and production reports, geologists and engineers can devise new strategies to improve well performance, weighing the costs of enhanced treatments against the expected benefits of increased production.

The fracturing fluid is recovered over the course of time. Because the toxicity of the fluid is a primary environmental concern, the degree and timing of recovery is a salient issue. Results vary by formation. Some rocks absorb more of the fluid than others. In some formations, a majority of the fluid flows back during the fracking process, while in others the balance of the water is recovered with the produced hydrocarbons over the course of subsequent weeks and months. In some cases fluid can be treated and reused, while in others disposal is preferred.¹⁵

Geologic conditions vary from region to region and even between formations within a region. These variations require a period of “learning by doing” as engineers experiment with the technical elements to crack the code of a particular formation and maximize production. For this reason, operators undertake multiwell projects, or drilling campaigns, to give engineers and geologists a chance to figure

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13. Service providers actively compete in providing additives. The exact combination of additives is fiercely protected as a trade secret by many servicing companies. These same companies typically bundle materials with consulting services to best apply inputs to a particular well.
 14. *See generally* Mike Vincent, *Examining Our Assumptions—Have Oversimplifications Jeopardized Our Ability to Design Optimal Fracture Treatments?*, SOC’Y PETROL. ENGINEERS (2010), <http://www.spe.org/dl/docs/2010/MikeVincent.pdf> (describing the many complexities obscuring accurate assessment of fracturing techniques).
 15. The cost of fresh water appears to be a major determinant of this decision at this time, but perceived environmental or regulatory costs could change the calculus for operators. *See* Christopher S. Kulander, *Shale Oil and Gas State Regulatory Issues and Trends*, 63 CASE W. RES. L. REV. 1101, 1105–07 (2013) (discussing the application of state water law to shale oil and gas well completion).

out how to optimize production.¹⁶ Many considerations affect well design decisions, and fracturing consultants are often retained.

A. *Microfracture-onomics*

Stimulating a reservoir by hydraulic fracturing increases the initial flow to the wellbore and the production of the well. A key to this process is the exposure of the wellbore to a large area of the reservoir. Consider for a moment the access that a perforated horizontal wellbore provides to the surface of the source rock. Comparing the formation surface area connected to the wellbore by perforations or fractures, the downhole surface area exposed to the reservoir can be increased by as much as several thousand times.¹⁷ Increasing the surface area allows production from less permeable (“tighter”) formations, which makes production from shales and other unconventional resources possible. Although more permeability is required for oil than gas, the advantage of well-designed and implemented fracture designs is tremendous—three to five orders of magnitude is not out of the question. The initial production of the well is a function of the initial pressure and exposed area: holding the reservoir pressure constant, fracturing the well can increase initial production rates by a factor similar to the increase in exposed area.

Consider the alternative to fracturing wells. Instead of increasing reservoir contact by fracking, operators could simply drill more wells. To match the contact provided by one fractured well, an operator would have to drill hundreds or thousands more wellbores. The return of these investments would be a fraction of the return rate with fracking. If the operator is trying to buy reservoir contact, drilling new well bores is dramatically more expensive than fracking.

Hydraulic fracturing has different effects in vertical and horizontal wells.¹⁸ The engineering subtlety of a detail such as proper proppant sizing indicates the difficulty of economic analysis. Correctly sized proppant costs about the same as the wrong size, in most cases, but

16. Rogers, *supra* note 2, at 129 fig.8.

17. The engineering term for this is “reservoir contact.” The author is indebted to John Getty of the Petroleum Engineering Lab at Montana Tech for this illustrative example. The hypothetical example is based on a typical, recent Bakken well with an 8000-foot lateral string. The contemplated fracture design is a thirty-stage program. The exact ratio is a function of fracture length and pressure applied. A ratio of 3200:1 is conservative given recent fracture designs. Successful multiple transverse fracture designs may achieve as much as two orders of magnitude *more* reservoir contact.

18. See Janie M. Chermak et al., Impacts of Hydraulic Fracturing and Completion Decisions on Shale Gas Well Productivity 30–31 (Oct. 16, 2012) (unpublished manuscript), *available at* <http://ssrn.com/abstract=2162486> (finding differences in how certain variables affect horizontal and vertical wells differently).

makes a large difference in well productivity.¹⁹ Differences within formations over time can be just as stark. The Bakken provides a good example as open-hole horizontal completions have given way to multistage jobs, with the number of stages now decreasing in an effort to balance returns and cost.

Initial flow rate is particularly important to the operator for two reasons. The first is that a high initial flow rate provides a large revenue stream. Developing oil and gas wells is capital-intensive, and the proceeds from a good well are a welcome fillip for cash flow. Operators, especially smaller independents that drill a majority of wells,²⁰ are heavily dependent on cash flow financing, which compounds the importance of initial production rates. This concern is especially true for drilling campaigns. One interesting difference between conventional and unconventional reservoirs is the higher variance in initial production rates for unconventional wells.²¹ This variance is due in part to the imprecise knowledge of unconventional reservoirs and the optimal application of fracking procedures. Thus, plenty of room remains for improvement in the understanding of how to most efficiently extract oil and gas from unconventional reservoirs. But it creates a financing risk for developers uncertain about future revenues.

Ultimate recovery is the final measure of the value of a well. The geophysics of extraction cause production to decline over time, so the ultimate recovery is a function of initial flow. The initial production level affects the total recovery. To the extent that reservoir stimulation increases initial flow, it also increases total recovery. But uncertain initial flow also implies that the ultimate recovery varies across wells, even within the same formation and lease. Once a well comes in, or begins producing, an operator can hedge some or all of the production risk in derivatives markets. This practice effectively trades future gas for current cash.

Well flow rates decline over time. The behavior of unconventional wells differs slightly from that of conventional wells. Fractured wells typically decline hyperbolically as opposed to exponentially.²² This

19. *Id.*

20. IHS GLOBAL INSIGHT, THE ECONOMIC CONTRIBUTION OF THE ONSHORE INDEPENDENT OIL AND NATURAL GAS PRODUCERS TO THE U.S. ECONOMY 41 (2011) [hereinafter IHS]. In 2009, independent oil and natural gas producers drilled 26,030 wells, compared to just 1,379 drilled by others. *Id.* at 41 tbl.19.

21. Henry D. Jacoby et al., *The Influence of Shale Gas on U.S. Energy and Environmental Policy*, 1 ECON. ENERGY & ENVTL. POL'Y 37, 40–41 (2012).

22. *Id.* at 40; see STANDARD HANDBOOK OF PETROLEUM AND NATURAL GAS ENGINEERING, *supra* note 7, § 7.1.4.1 (explaining the difference between an exponential decline curve and a hyperbolic decline curve);

means that the initial decline rate is high relative to a conventional well, but that production levels off and continues instead of continuing to diminish. This pattern makes the early production all the more important.

A significant but still unproven feature of unconventional wells is the ability to restimulate the reservoir over the course of time. Hydraulic fracturing was initially developed as a reservoir stimulation treatment. The ability to refracture a reservoir and increase production for some period of time after initial production potentially gives rise to a very different pattern of development. Some success has been observed with reentry and restimulating wells in unconventional formations like the Barnett Shale in Texas and in the Wattenberg field in Colorado.²³ But the future of “factory” models of production, in which one well is restimulated every few years, with little reduction in the initial flow rate across the treatments, is still speculative. Combined with pad drilling, which takes advantage of directional drilling capability to group several wells together on the surface, fracking could potentially shift the nature of oil and gas development from a large number of one-off wells to clusters of continually productive assets.

B. Macrofrackonomics

Technical innovation in the application of hydraulic fracturing and related technologies has transformed the outlook for domestic oil and gas production in the United States. Oil and gas resources are extensive, but the uncertainty about the location, feasibility, and profitability of extraction defines the economic decisions regarding resource use. As an example, shale deposits are widespread, but the value of the resource is not clear from the physical availability. Forecasts can vary widely depending on the definition of resources; this Article adopts a conservative approach to defining oil and gas resources.²⁴ Three measures capture the impact of new technology: economic reserves, a measure of the abundance of hydrocarbon resources; production, or the flow of resources into the economy; and prices, which measure the relative scarcity of oil and gas. Drilling investments are a related measure. The cheap abundance of natural

Rogers, *supra* note 2, at 127 (noting the rate of well production decline in the Barnett Shale).

23. Rogers, *supra* note 2, at 128; Vello A. Kuuskraa, *Fostering Continuing Innovation in Unconventional Oil and Gas*, U.S. ASS'N FOR ENERGY ECON. (Oct. 11, 2011), <http://www.usaee.org/usaee2011/submissions/presentations/kuuskraa.pdf>.

24. For a discussion about competing estimates of the resource base and about how proved reserves is a conservative measure, see Vello A. Kuuskraa, *Resource Potential Estimates Likely to Change*, OIL & GAS J., Sept. 17, 2007, at 64.

gas has global environmental implications as cleaner-burning gas replaces other sources of energy.²⁵

The net result of combined technological change has been to drastically increase the U.S. economic reserves of both oil and natural gas. Economic reserves are defined as the physical quantity of resource that is known and could be profitably produced given current technology and prices. Technological progress is likely to expand the physical amount of resources that can be extracted profitably. But the impetus for technical innovation in nonrenewable resource markets may be reaction to relative scarcity, so it is not clear that technical change is exogenous. This Article's primary concern is not about the exact timing of the changes in reserves, production, and prices. A casual analysis of the problem is sufficient.

Economic reserves evolve in at least three known ways. First, if additional resources are discovered or if known resources become recoverable thanks to technological advances, the reserve base increases. Second, the force of depletion works in the opposite direction by reducing reserves. Oil and gas are naturally nonrenewable resources, and therefore the production of oil and gas reduces the total amount left for the future. The net effect of these two forces is a question of considerable interest to natural resource economists, and the net effect is different for oil and gas.²⁶ The third force at work on economic reserves is price. If prices rise for some exogenous reason (for example, a politically induced supply shock elsewhere in the world), then some resources that were not economically feasible at a lower price may become profitable to recover. Conversely, a price fall might cause operators to shut in marginal production to save the resource for a more favorable price environment.

1. Reserves

Natural gas occurs by itself and in association with crude oil or other types of hydrocarbons. Different sources of natural gas reserves, such as associated or wet gas deposits, are tracked in terms of dry natural gas content. Various types of natural gas reserves are then aggregated into a total reserve base at any point in time. This aggregation is not a problem because the different sources yield the same products after processing.

25. See Jacoby et al., *supra* note 21, 44–50 (acknowledging that shale production may help reduce greenhouse gas emissions while cautioning that shale production may stunt the development of cleaner technologies).

26. See John T. Cuddington & Diana L. Moss, *Technological Change, Depletion, and the U.S. Petroleum Industry*, 91 AM. ECON. REV. 1135, 1143–44 (2001) (finding that technological change in the past few decades has reduced the exploration and development costs for natural gas more than it has for crude oil).

Petroleum differs from natural gas in that crude oil comes in a variety of different grades. Prices are often reported for particular grades at specified locations, such as West Texas Intermediate at Cushing, Oklahoma. Price differences are determined by refining cost and yield, as well as transportation basis. Calculation of oil reserves requires aggregating the physical volume of different crude streams without correcting for the different value of alternative streams. The refining process makes the same products from different crude streams, though in slightly different proportions.

Other hydrocarbon resources are important to estimating the value of hydraulic fracturing. Unconventional resources are often rich in natural gas liquids (NGLs), or liquids found with natural gas that are not crude oil. This category includes important chemical feedstocks such as ethane and butane as well as other consumer products like propane and natural gasoline. Previously classified as lease condensate, these products can command a price premium and are marketed separately. Aggregating NGLs has the same issues as crude oil due to natural variation in input composition. À la carte pricing of constituent products makes the value of NGLs highly dependent on their makeup. Refining byproducts known as natural gas plant liquids are a substitute for lease-level NGLs.

Figure 1 depicts the fluctuation in U.S. proved reserves for oil and natural gas. The last ten years of the series show a dramatic increase in natural gas reserves. The timing of the increase in natural gas reserves coincides with the timing of technical innovations for unconventional resources that have since entered the reserve base. The increase is not instantaneous because of the necessary time to prove the economic viability of various unconventional resources. More speculative measures of reserves, such as inferred or probable reserves, are sometimes used, but here the more conservative proved reserves are reported.

The magnitude of the increase represents nearly a doubling in the reserve base and has pushed domestic natural gas reserves to an all-time high. The higher market value of natural gas—in the wake of regulatory reforms that have de-balkanized the natural gas market²⁷—is an important consideration when comparing the absolute magnitude of reserves over time. The drastic effect on the natural gas reserve base has been referred to as the “natural gas revolution.”²⁸ The reserve-to-production ratio has risen from a low of 6.9 in 1998²⁹

27. See JAMES H. MCGREW, FERC: FEDERAL ENERGY REGULATORY COMMISSION 61–70 (ABA Basic Practice Ser., 2d ed. 2009) (providing a brief history of natural gas industry regulation).

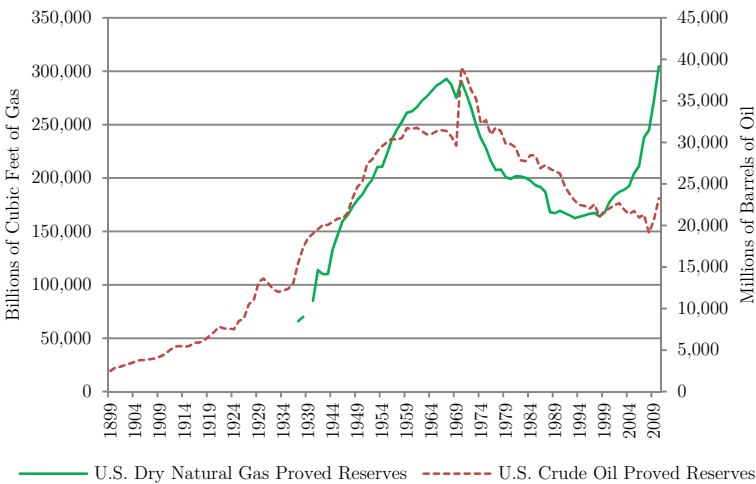
28. See, e.g., YERGIN, *supra* note 4, at 325.

29. In 1998, U.S. proved natural gas reserves were 164.041 trillion cubic feet, and production was 23.924 trillion cubic feet. *U.S. Natural Gas*

to 11.4 in 2010.³⁰ This additional reserve growth beyond production growth has led some pundits to describe the U.S. natural gas situation as a hundred-year gas supply.³¹

Oil reserves have increased less than gas, though a reserve addition of approximately 10 percent occurred from 2006 to 2010.³² In part this increase is due to the later application of hydraulic fracturing to oil reservoirs. Technology developed for gas-rich shale formations has been expanded to oil-rich shale formations such as the Bakken in North Dakota and Montana as well as the Eagle Ford in Texas.

*Figure 1: Oil and Natural Gas Proved Reserves 1899–2010*³³



Reserves Summary as of Dec. 31, U.S. ENERGY INFO. ADMIN., http://www.eia.gov/dnav/ng/xls/NG_ENR_SUM_DCU_NUS_A.xls (last updated Aug. 2, 2012) [hereinafter *Natural Gas Reserves*]; U.S. ENERGY INFO. ADMIN., NATURAL GAS ANNUAL 1998 at 4 tbl.1 (1999).

30. In 2010, proved natural gas reserves were 304.625 trillion cubic feet, and production was 26.816 trillion cubic feet. *Natural Gas Reserves*, *supra* note 31; U.S. ENERGY INFO. ADMIN., NATURAL GAS ANNUAL 2011 at 1 tbl.1 (2013).
31. See, e.g., POTENTIAL GAS COMM., POTENTIAL SUPPLY OF NATURAL GAS IN THE UNITED STATES (2012). Such predictions use less conservative measures than proved reserves, including probable, possible, and speculative reserves.
32. *U.S. Crude Oil Proved Reserves*, U.S. ENERGY INFO. ADMIN., http://www.eia.gov/dnav/pet/hist_xls/RCRR01NUS_1a.xls (last updated Aug. 2, 2012).
33. *Id.*; see also *Natural Gas Reserves*, *supra* note 31 (spreadsheet showing proved reserves from 1925 to 2010).

2. Production

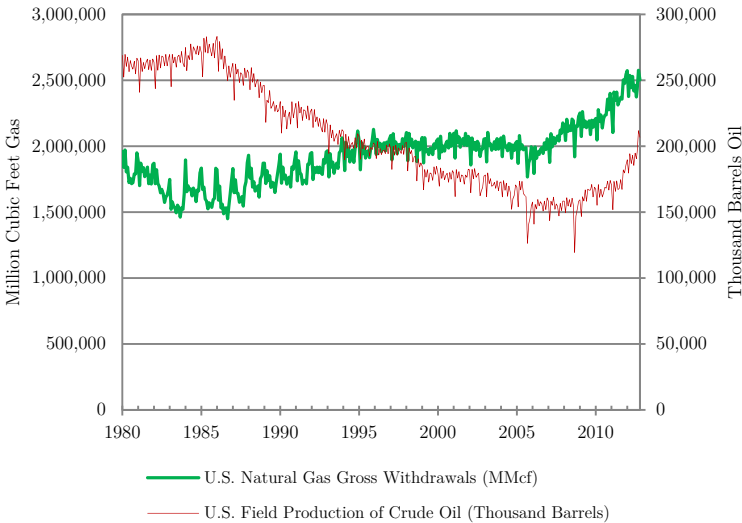
Figure 2 shows monthly production of oil and gas in the United States. In addition to reserve growth, domestic natural gas production has increased in recent years. An important portion of demand growth has been for gas-fired electricity generation. This new demand has been in response to both technical innovation in the form of new natural gas turbines and increasing regulation of coal-fired generation. Production of natural gas liquids has been an important component in the rate of return from shale gas. Because of the several sources of these products, reliable and continuous production data are not available.

The strong price environment for oil over the past few years has provided an incentive for operators to locate new wells and bring them into production. This pushed operators into more costly environments, including the deepwater Gulf of Mexico. Production has responded after a long, steady decline. The response has been pronounced in unconventional oil. North Dakota, powered by oil from the Bakken Shale, is now the second-highest producing state after Texas.³⁴ At the same time, the conventional fields in California and Alaska have continued to decline.³⁵

34. *Crude Oil Production*, U.S. ENERGY INFO. ADMIN., http://www.eia.gov/dnav/pet/pet_crd_crpdn_adc_mbbldpd_a.htm (last updated Mar. 15, 2013). Texas produced the most barrels of crude oil per day in 2012 (1,971,000), while North Dakota produced the second most (663,000).

35. *Id.*

Figure 2: Oil and Natural Gas Production 1980–2013³⁶



3. Prices

The growth in reserves and production has had dramatic price effects in the natural gas market.³⁷ This is due to the physical nature of natural gas. Unlike crude oil or propane, which can move by alternative means such as truck or rail, natural gas is limited to pipeline transport. Distribution networks are therefore limited. International trade in natural gas depends on terrestrial pipeline connections to Canada and Mexico and specialized liquefied natural gas (LNG) shipment facilities for ocean transport. The United States has a very limited capacity for LNG imports, and export capacity is

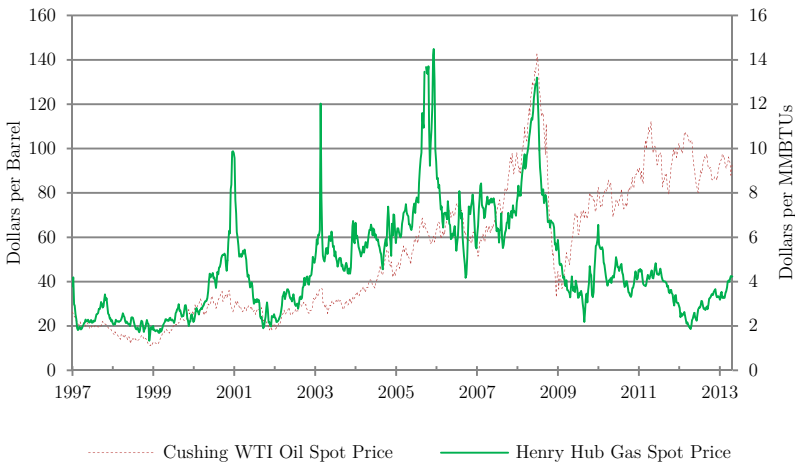
36. For the oil production data utilized for the creation of Figure 2, see *U.S. Field Production of Crude Oil*, U.S. ENERGY INFO. ADMIN. (Apr. 29, 2013), http://www.eia.gov/dnav/pet/hist_xls/MCRFPUS1m.xls. For the natural gas production data utilized for the creation of Figure 2, see *U.S. Natural Gas Gross Withdrawals*, U.S. ENERGY INFO. ADMIN., http://www.eia.gov/dnav/ng/hist_xls/N9010US2m.xls (last updated Apr. 30, 2013). Reporting of such data is required by the Federal Energy Administration Act of 1974. See U.S. ENERGY INFO. ADMIN., MONTHLY NATURAL GAS PRODUCTION REPORT: FORM EIA-914, available at http://www.eia.gov/survey/form/eia_914/form.pdf; U.S. ENERGY INFO. ADMIN., MONTHLY NATURAL GAS LIQUIDS REPORT: FORM EIA-816, available at http://www.eia.gov/survey/form/eia_816/form.pdf; U.S. ENERGY INFO. ADMIN., FORM EIA-182: DOMESTIC CRUDE OIL FIRST PURCHASE REPORT, available at http://www.eia.gov/survey/form/eia_182/form.pdf.

37. Compare *supra* Figure 2, with *infra* Figure 3.

currently being constructed or converted.³⁸ Increased domestic production must therefore be absorbed by the market or fixed storage facilities. Flooding the market with natural gas has helped to depress natural gas prices from earlier levels.

In contrast to gas, oil is fungible and is traded on a global market. The U.S. imports large quantities of oil both from North American neighbors and via ocean-going vessels. The United States is an exporter of refined petroleum products. The fungibility of oil is imperfect, or more precisely, costly. The expansion of oil production in areas of the U.S. without existing infrastructure links (e.g., North Dakota) has contributed to a basis differential between the continental pricing point at Cushing, Oklahoma, and coastal prices such as the Brent price, the more widely-accepted global benchmark price of crude oil.³⁹ Because U.S. oil production is a relatively small share of global oil production, domestic increases have little effect on prices. Oil prices are determined on a global market.

*Figure 3: Oil and Natural Gas Prices 1997–2013*⁴⁰



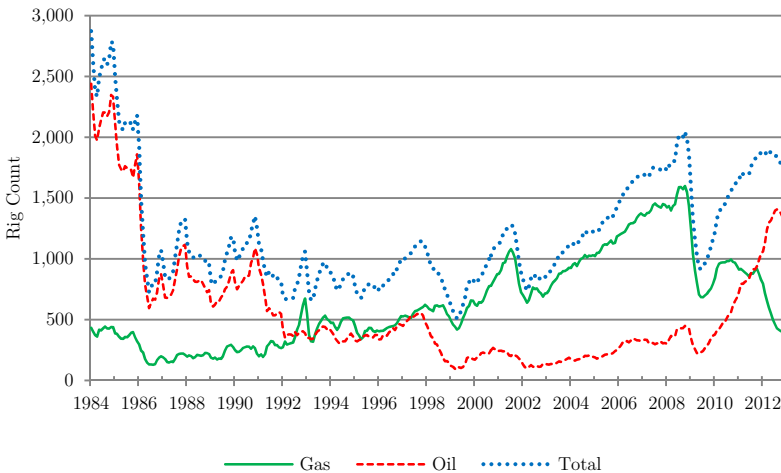
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38. For a review of the U.S. LNG situation, see KENNETH B. MEDLOCK III, U.S. LNG EXPORTS: TRUTH AND CONSEQUENCE 21 (2012), available at http://www.bakerinstitute.org/publications/US%20LNG%20Exports%20-%20Truth%20and%20Consequence%20Final_Aug12-1.pdf.
39. See Severin Borenstein & Ryan Kellogg, *The Incidence of an Oil Glut: Who Benefits from Cheap Crude Oil in the Midwest?*, 34 ENERGY J. (forthcoming Sept. 2013).
40. For the oil pricing data utilized for the creation of Figure 3, see *Cushing, OK WTI Spot Price FOB*, U.S. ENERGY INFO. ADMIN. (May 5, 2013), http://www.eia.gov/dnav/pet/hist_xls/RWTCD.xls. For the natural gas pricing data utilized for the creation of Figure 3, see *Henry Hub Gulf Coast Natural Gas Spot Price*, U.S. ENERGY INFO. ADMIN. (May 5, 2013), http://www.eia.gov/dnav/ng/hist_xls/RNGWHHDd.xls.

When NGL price premia were relatively large and positive, many operators flooded into “liquid-rich” plays like the Eagle Ford shale in Texas.⁴¹ As the price premia have deteriorated due to increased supply, operators have chased petroleum and sought innovative means to deliver their product to locations with local price premia.

4. Drilling

Price expectations have affected decisions by operators about where to drill and how much to drill. The number of drilling rigs actively working on oil and gas wells fluctuates over time, as Figure 4 shows. More drilling occurs when prices are high and are expected to stay high, whereas rigs are idled when prices are less favorable. Rig counts are considered leading indicators of production, though the risk that holes will be unprofitable is quite real. The long-term cycles in oil and gas drilling are evident from the rig count. Starting in the late 1990s more and more rigs were deployed in search of natural gas. Since 2009, as the value of hydraulic fracturing has been demonstrated, such as in the Bakken Shale, many rigs have converted to relatively more valuable oil in preference to gas.

*Figure 4: Oil and Natural Gas Rig Counts 1984–2013*⁴²



41. Harry R. Weber, *Eagle Ford to get Big Play from Marathon*, HOUS. CHRON. (Dec. 4, 2012, 6:44 PM), <http://www.chron.com/business/energy/article/Eagle-Ford-to-get-big-play-from-Marathon-4091172.php> (describing Marathon’s plan to expend “more than a third of its \$5.2 billion capital budget for 2013” on beginning operations into the Eagle Ford Shale).

42. Smith Bits STATS provides information on rig counts. See *Rig Count History*, SMITH STATS, <http://stats.smith.com/new/history/statshistory.htm> (last visited Apr. 15, 2013) (individual spreadsheets by quarter for download for each year).

A counterfactual to the use of fracking is difficult to consider given its widespread adoption throughout the oil and gas industry. In the past year or two, debate has shifted from consideration of a ban to discussion about an adequate regulatory framework for the process. The regulatory debate hinges on the economic contribution on local, regional, national, and global scales. One study speculates that with severe restrictions on the use of fracking, gas production would fall by 17 percent despite a higher price environment, with the majority of the reduction coming from unconventional resources.⁴³

C. Costs

The physical gains from hydraulic fracturing are impressive, but the costs of the process have to be considered in a full accounting. Focusing on onshore wells, a back-of-the-envelope calculation attributes 25 percent of drilling costs to the fracturing and completion. Over the period from 2006 to 2010, the average number of wells drilled per year was 43,237, with an average cost of \$2.38 million per well.⁴⁴ Twenty-five percent of that is \$595,000, with a range from \$345,000 to \$863,000. This calculation assumes that every single well drilled is fractured, so it represents a lower bound on servicing costs. More expensive wells, such as deep horizontal wells, often have more expensive fracturing jobs. A typical Bakken well costs \$8–10 million with about \$1.5–2.5 million in fracking cost. The increased production from such wells needs to offset the higher drilling costs. The panoply of completion options available to operators increases the variance in costs.

Figure 5 depicts the average cost of new wells of all types at all locations in the United States. The costs are normalized to 2000 dollars so that all years are comparable. The increase in drilling costs is marked, particularly since the late 1990s.⁴⁵ An alternative explanation of these data immediately presents itself—drilling costs could be increasing because wells are getting deeper. If we are seeking a nonrenewable resource like oil, it seems practical to drill the relatively cheaper shallow deposits first.⁴⁶ The real cost per foot drilled

43. VAUGHAN & PURSELL, *supra* note 10, at 7.

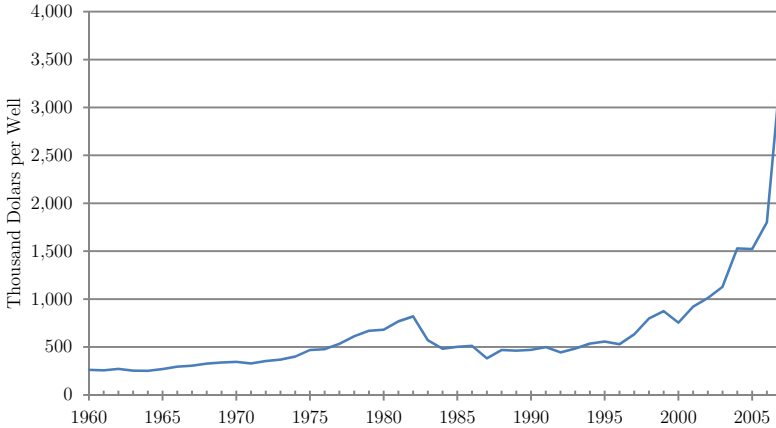
44. The total number of wells was 51,787 in 2006, 52,169 in 2007, 55,096 in 2008, 32,462 in 2009, and 27,409 in 2010, but the 2010 total may increase due to a lag in reporting. IHS, *supra* note 20, at 41. The total cost of wells drilled was \$98.6 billion in 2006, \$124 billion in 2007, \$164 billion in 2008, \$108 billion in 2009, and \$106 billion in 2010. *Id.* at 43.

45. See *infra* Figure 5.

46. Economists usually refer to this as the Herfindahl Principle, though it has been demonstrated not to hold theoretically and empirically. For helpful background material on the Herfindahl Principle, see generally Eric Iksoon Im et al., *Discontinuous Extraction of a Nonrenewable Resource*, 90 ECON. LETTERS 6 (2006).

is an alternative measure. That series shows a similar trend to the total well cost (though at a slightly slower rate because wells are also becoming deeper).⁴⁷

Figure 5: Cost per Well Drilled 1960–2007⁴⁸



Two major methodological changes are driving the increase. In order to use more advanced drilling techniques such as directional and horizontal drilling, larger and more sophisticated rigs must be used. Such rigs have higher rates (on a day or footage basis). Second, stimulating the reservoir prior to first production, or fracking the well, adds to the drilling costs. Because almost all wells are fractured, part of the increase in drilling costs is attributable to fracking. An example of both factors (more extensive rig and more fracking) is a shift from \$2 million to \$5–6 million per well in the Woodford Shale of Southeast Oklahoma.⁴⁹

A concern about the data presented in Figure 5 is the timing of the end of the series. Factor prices respond to demand, but it takes time to adjust capital levels and prices might therefore be sticky. For example, replacing the rig inventory to accommodate larger rigs

47. The cost in dollars per foot of all wells drilled has increased as follows: \$187.46/foot in 2002, \$203.25/foot in 2003, \$267.28/foot in 2004, \$271.16/foot in 2005, \$324.00/foot in 2006, and \$574.46/foot in 2007. *Costs of Crude Oil and Natural Gas Wells Drilled*, U.S. ENERGY INFO. ADMIN. (Sept. 7, 2012), http://www.eia.gov/dnav/pet/xls/PET_CRD_WELLCOST_S1_A.xls. The cost per foot for only natural gas wells has increased as follows: \$175.78/foot in 2002, \$189.95/foot in 2003, \$284.78/foot in 2004, \$280.03/foot in 2005, \$348.36/foot in 2006, and \$604.06/foot in 2007. *Id.*

48. *Id.*

49. Michael Godec et al., *Economics of Unconventional Gas* 6 (Oil & Gas J., Unconventional Gas Article No. 5, 2007).

capable of handling deep horizontal wells takes time, and in the short run available rigs might command a premium. If 2007 was the peak of the boom, then, over time, costs might have subsided, reflecting a temporary shortage of capital rather than a long-term change in cost due to different technology. Unofficial data in the years since 2007 confirm the spike in drilling costs, but the costs have not returned to levels observed in the 1970s and 1980s.⁵⁰

Well servicing is a concentrated industry, which raises the possibility of market power. A few large firms dominate the fracking business: Halliburton, Schlumberger, BJ, and Sanjel enjoy prominent positions.⁵¹ Smaller but growing companies include FTS, Cal Frac, Weatherford, Pumpco, and Trican. Other firms are growing regionally and may become important players in coming years. Certainly there are differentiated products in the provision of fracking services, as companies actively advertise the superiority of their own fluids and consulting services. Determining market power is a more involved process requiring a detailed study of the industry.

Hydraulic fracturing is one of several services provided by firms specializing in “field services.” A wide range of contracts are used to compensate these firms. One difficulty in accounting the cost of fracturing is that well service contracts are often long term and field-wide. A single contract is negotiated that covers more than one well over time and space. Some of the contracts are share contracts, either as overrides or as farm-ins. In such a case the final compensation to the service crew is a function of the productivity of the well. This provides a strong incentive for the servicer to perform. But contract

50. IPAA reports nominal per foot drilling costs rising to \$671.87 in 2009 before falling to \$302.21 in 2010. *Industry Statistics*, INDEP. PETROL. ASS'N AM., <http://www.ipaa.org/economics-analysis-international/industry-statistics/?c=Chart17> (last visited Apr. 13, 2013). This is still 65 percent above 1998 levels in real terms. *Id.*

51. Halliburton, Schlumberger, and BJ have a 75 percent U.S. market share for the high pressure pumps needed for fracking. Rogers, *supra* note 2, at 132. Another indication of market prominence is that these same three companies entered into a memorandum of understanding with the EPA on December 12, 2003. Memorandum of Agreement between The United States Environmental Protection Agency and BJ Services Company, Halliburton Energy Services, Inc., and Schlumberger Technology Corporation on Elimination of Diesel Fuel in Hydraulic Fracturing Fluids Injected into Underground Sources of Drinking Water During Hydraulic Fracturing of Coalbed Methane Wells (Dec. 12, 2003), available at http://www.epa.gov/ogwdw/uic/pdfs/moa_uic_hyd-fract.pdf. The intention was “to eliminate diesel fuel in hydraulic fracturing fluids injected into coalbed methane (CBM) production wells in underground sources of drinking water (USDWs) and, if necessary, select replacements that will not cause hydraulic fracturing fluids to endanger USDWs.” *Id.* § I.A.

form is itself a choice, and may bias estimates of the value of fracking operations.

II. REGULATORY AND ENVIRONMENTAL CONSIDERATIONS

A. Regulation

Current regulatory debate about hydraulic fracturing has focused on the merits of federal versus state regulation. At this point the primary authority for regulation of oil and gas development and hydraulic fracturing is at the state level.⁵² Different states have adopted different strategies for regulating fracking, based in large part on experiences in each state.⁵³ The long experience of Texas in oil and gas law and its position as an early hotbed of shale gas development make its law and regulation a model for many other states.⁵⁴

The prospect of external regulation has helped companies recognize that preemptive self-regulation might be a preferable outcome.⁵⁵ A step in this direction is the self-reporting of chemicals used during fracking operations in specific areas by service companies

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52. “State oil and gas commissions review well permits. This review addresses legal and engineering criteria such as well construction and spacing.” Timothy Fitzgerald, *Hydraulic Fracturing in Context: Key Institutional Features of an Evolving Technology*, U.S. ASS’N FOR ENERGY ECON. DIALOGUE (2011), http://dialogue.usaee.org/index.php?option=com_content&view=article&id=142:hydraulic-fracturing-in-context-key-institutional-features-of-an-evolving-technology&catid=48:volume-19-number-2&Itemid=557.
53. Several summaries of state regulations are available. *E.g.*, Kulander, *supra* note 15; Res. for the Future, *A Review of Shale Gas Regulation by State*, CENTER FOR ENERGY ECON. AND POL’Y, http://www.rff.org/centers/energy_economics_and_policy/Pages/Shale_Maps.aspx (last visited Apr. 16, 2013); *see also* Groundwater Prot. Council & Interstate Oil and Gas Compact Comm’n, *Regulations By State*, FRACFOCUS CHEMICAL DISCLOSURE REGISTRY (2013), <http://fracfocus.org/regulations-state> (providing links to summaries and regulations for each state).
54. *See* Dianne Rahm, *Regulating Hydraulic Fracturing in the Shale Gas Plays: The Case of Texas*, 39 ENERGY POL’Y 2974, 2974 (2011) (“Texas is a major player in these [new shale gas drilling] developments and is forecast to be the key state contributing to U.S. natural gas supplies in the future.”); Travis Zeik, Note, *Hydraulic Fracturing Goes to Court: How Texas Jurisprudence on Subsurface Trespass Will Influence West Virginia Oil and Gas Law*, 112 W. VA. L. REV. 599, 600 (2010) (“West Virginia has yet to hear a controversy involving hydraulic fracturing but the West Virginia court would most likely follow the lead of the Texas court.”).
55. At least in theory, self-regulation would make sense. *Cf.* Robert Innes, *Violator Avoidance Activities and Self-Reporting in Optimal Law Enforcement*, 17 J.L. ECON. & ORG. 239 (2001) (discussing the optimum regulatory enforcement level in the law that will encourage self-reporting).

to FracFocus, an online repository of information about hydraulic fracturing jobs.⁵⁶ This partnership between the Interstate Oil & Gas Compact Commission and the Groundwater Protection Council has proven to be a comfortable compromise for operators. On one hand they would like to release information and reduce public pressure for more information about the fracking process. On the other, these operators regard their precise recipes for fracturing fluids as proprietary information⁵⁷ and do not want to dissipate the advantage of exclusive use of precise combinations of chemicals that increase well production.

B. *Environmental Costs*

As hydraulic fracturing has made new resources attractive, many communities unfamiliar with extensive oil and gas development have been introduced to it. The combination of the appearance of development and the usage of a relatively new and rapidly evolving technology has stiffened public resistance to change. Concerned residents and environmentalists have struggled to understand the environmental costs of fracking. In contrast to the aggregate effects technology adoption has for energy markets, or the microfractures that allow increased productivity, the environmental concerns are on a local scale.⁵⁸ Residents worry about local gas or oil wells contaminating water wells, or road damage and traffic caused by service crews, or the effect on local air quality of emissions.⁵⁹

Regulation of fracking has been widely considered, particularly in response to grassroots concerns about environmental quality. But definitive evidence of damages *due to fracturing* and not the result of other accidents associated with the development process has been difficult to obtain. In part this is because fracking occurs far underground, where verification is costly if not impossible. Other

56. FRAC FOCUS CHEMICAL DISCLOSURE REGISTRY, www.fracfocus.org (last visited Apr. 16, 2013).

57. For an interesting discussion on the issue of secrecy and how it relates to regulation, see Hannah Wiseman, *Trade Secrets, Disclosure, and Dissent in a Fracturing Energy Revolution*, 111 COLUM. L. REV. SIDEBAR 1 (2011).

58. Megan Boehnke, *Environmental Groups Seek to Block UT's Fracking Proposal*, KNOXNEWS.COM (Jan. 29, 2013, 11:00 PM), <http://www.knoxnews.com/news/2013/jan/29/environmental-groups-seek-to-block-uts-fracking>.

59. See Lynne Peeples, *Fracking Pollution Sickens Pennsylvania Families, Environmental Group Says*, HUFFINGTON POST (Oct. 18, 2012, 6:26 PM), http://www.huffingtonpost.com/2012/10/18/fracking-pollution-pennsylvania_n_1982320.html (explaining public health concerns with fracking in Pennsylvania).

accidents, such as surface spills or well blowouts, are much easier to observe and address than the direct impacts of fracking itself.

In the absence of confirmed evidence, anecdotes have filled the gap. Changes are certainly observable, even when they are not verifiable. This is often due to the absence of adequate baseline data to demonstrate damages. Residents of otherwise somnolent places like Silt, Colorado,⁶⁰ and Dimock, Pennsylvania,⁶¹ have witnessed changes in groundwater quality. Many other locations around the country have observed spills, changes, and irregularities.⁶² Those observations have increased calls for regulation, but before effective regulations are imposed, some causation needs to be determined.

Despite studies suggesting a link between toxic groundwater contamination and fracturing fluid,⁶³ the demonstrated subsurface impact comes in a slightly different form. Instead of finding chemical additives, a different study found methane in shallow water wells in the vicinity of deep shale gas wells.⁶⁴ The explicit pathway for this

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60. As early as 2001, families in Silt began to report “contamination of their drinking water during hydraulic fracturing of four nearby natural gas wells owned by Ballard Petroleum.” Later, benzene was confirmed to be present in a Silt resident’s water. See *Water Contamination*, SAVE COLO. FROM FRACKING (May 11, 2010), <http://www.savecoloradofromfracking.org/harm/waterquality.html>.
61. See Christopher Bateman, *A Colossal Fracking Mess*, VANITY FAIR, (June 21, 2010), <http://www.vanityfair.com/business/features/2010/06/fracking-in-pennsylvania-201006>.
62. VAUGHAN & PURSELL, *supra* note 10, at 24–27 (listing a number of incidents that have triggered public backlash against fracking).
63. See, e.g., Tom Myers, *Potential Contaminant Pathways from Hydraulically Fractured Shale to Aquifers*, 50 GROUND WATER 872 (2012) (concluding that fracking can contaminate aquifers by releasing fluids from the shale and providing methods for testing postfractured shale). For a response to Myers, see James E. Saiers & Erica Barth, *Discussion of Potential Contaminant Pathways from Hydraulically Fractured Shale to Aquifers by T. Myers*, 50 GROUND WATER 826 (2012) (cautioning that Myers used some questionable assumptions and asserting that “additional field measurements [are] needed to parameterize and calibrate appropriately formulated models”). *But see* Harvey A. Cohen et al., Comment, *Discussion of Potential Contaminant Pathways from Hydraulically Fractured Shale to Aquifers by T. Myers*, 51 GROUND WATER (forthcoming 2013) (strongly arguing against Myers’ conclusion being flawed).
64. The initial study was conducted by Stephen Osborn. See Stephen G. Osborn et al., *Methane Contamination of Drinking Water Accompanying Gas-Well Drilling and Hydraulic Fracturing*, 108 PROC. NAT’L ACAD. SCI. 8172 (2011) (observing methane concentrations in groundwater near gas wells, calling for more research on methane contamination, and suggesting that data collection concerning groundwater and methane should be done throughout drilling operations to allow for further conclusions). Nathaniel Warner conducted a follow-

contamination is unknown, though poor well cementing practices are suspected. Identifying the causal pathway is a challenge, but the discovery itself poses a different problem for environmentalists concerned with contamination. Certainly water users do not want methane in their water—at the least it is an inconvenience, at worst a safety hazard (though health concerns are not especially strong). What is more problematic is that some water wells have naturally occurring methane. Without evidence about different damages from thermogenic and biogenic methane in drinking water, the appearance of deep methane in drinking water does not in itself seem to present a novel damage. The more salient concern is that if methane appears from an unknown source, perhaps other toxic substances are also finding their way into drinking water supplies.

C. *Pavillion, Wyoming*

Pavillion, Wyoming, is an unlikely setting for the front line of the dispute over hydraulic fracturing. It is a quiet place well off the beaten path—there are fewer than 250 residents of the town in a high, arid basin.⁶⁵ The broader area has had some oil and gas development for decades; the earliest wells were drilled in the 1960s.⁶⁶ There are two reasons why Pavillion is an appropriate location to test for

up study that may have provided support for concerns that both methane and fracking fluid could travel into groundwater as a result of fracking. See Nathaniel R. Warner et al., *Geochemical Evidence for Possible Natural Migration of Marcellus Formation Brine to Shallow Aquifers in Pennsylvania*, 109 PROC. NAT'L ACAD. SCI. 11,961 (2012) (finding that some Marcellus Shale formations have preexisting connectivity pathways that could be a concern for drinking water contamination). Others have doubts about these results. Samuel C. Schon, Letter, *Hydraulic Fracturing Not Responsible for Methane Migration*, 108 PROC. NAT'L ACAD. SCI. E664 (2011) (claiming that Osborn's finding of methane concentrations near gas wells is due to natural processes); Terry Engelder, Letter, *Capillary Tension and Imbibition Sequester Frack Fluid in Marcellus Gas Shale*, 109 PROC. NAT'L ACAD. SCI. E3625 (2012) (claiming that Warner's worries about fracking fluids travelling through natural pathways are overstated). Warner responded to Engelder's dismissal of his claim. See Nathaniel R. Warner et al., Letter, *Reply to Engelder: Potential for Fluid Migration from the Marcellus Formation Remains Possible*, 109 PROC. NAT'L ACAD. SCI. E3626 (2012) (explaining the findings of their study and pointing out flaws in Engelder's response).

65. Additional background information on the area and the issues that arose can be found in EPA, INVESTIGATION OF GROUND WATER CONTAMINATION NEAR PAVILLION, WYOMING PHASE V SAMPLING EVENT, (2012) [hereinafter EPA SUMMARY]. See also PETER FOLGER ET AL., CONG. RESEARCH SERV., R 42327, THE EPA DRAFT REPORT OF GROUNDWATER CONTAMINATION NEAR PAVILLION, WYOMING 2–5 (2012), available at <http://wyofile.com/wp-content/uploads/2012/01/R42327-2.pdf>.

66. FOLGER ET AL., *supra* note 65, at 5.

impacts of hydraulic fracturing. First, the state and the immediate area are both familiar with oil and gas development from a long history. Thus, complaints about damages from fracking are easier to distinguish from complaints about development in general. This allows isolation of fracking as the proximate cause. Second, a number of physical factors outlined below make Pavillion a potentially more convincing example of damage from the fracturing process itself.

Development of new wells preceded complaints by residents of degraded well quality.⁶⁷ Well users reported objectionable taste and odor that had not previously been an issue. In 2008 the U.S. Environmental Protection Agency (EPA) agreed to launch an investigation into the reported groundwater contamination after the operator conducted two years of tests that did not satisfy the residents.⁶⁸ The area in which the study focused was northeast of the town of Pavillion. Two groundwater monitoring wells were drilled to test groundwater quality for contamination in June of 2010.⁶⁹

Wyoming Oil and Gas Conservation Commission records indicate a total of 125 wells capable of producing in the immediate vicinity of the groundwater monitoring wells.⁷⁰ The mineral ownership is divided between tribal, federal, and private ownership. In many cases surface owners do not own the minerals under their land. While some of these wells were drilled in earlier decades, a large number of the wells were drilled in the early 2000s and were completed with fracturing treatments to access the tight sands of the Wind River and Fort Union formation. All of the active wells are now operated by Encana USA, a larger independent company that has aggressively pursued unconventional resources in several states.⁷¹

Four factors conspire to make the Pavillion area a likely spot for problematic fracturing jobs. First, the bulk of the servicing jobs were

67. *See id.* at 6.

68. *Id.* at 1.

69. *Id.* at 4.

70. The area described is a nine-square mile portion of Township 3N, Range 2E. The EPA monitoring wells are in sections 10 and 12, respectively. This subarea covers most of the 169 production wells cited in the EPA's draft report. EPA, DRAFT: INVESTIGATION OF GROUND WATER CONTAMINATION NEAR PAVILLION, WYOMING 1 (2011) [hereinafter EPA DRAFT REPORT].

71. Encana only drilled the wells that have been constructed since 2004. The earlier wells were drilled by Tom Brown, Inc., which Encana acquired in 2004. More information on Encana's history in the field is available in a document indicating Encana's stance on the groundwater contamination in Pavillion, Wyoming. *See* News Release, Encana, Why Encana Refutes U.S. EPA Pavillion Groundwater Report (Dec. 12, 2011) [hereinafter Encana], <http://www.encana.com/news-stories/news-releases/details.html?release=632327>.

done at a relatively early stage in the technological diffusion.⁷² Technical understanding and control is increasing over time, so these earlier jobs may have been less precise. The open-hole completions used in many of the wells have the lowest degree of control over fracture propagation. Second, the fracturing took place at a relatively shallow depth—as shallow as 1220 feet below the surface.⁷³ Third, groundwater is relatively deep in the area, with water wells extending as deep as 800 feet below the surface.⁷⁴ This leaves a relatively narrow vertical horizon separating the bottom of water wells and the shallowest fractures; for contrast consider the situation in a typical Bakken or Marcellus well where there are thousands of feet of rock between the fractured region and groundwater. Fourth, some of the gas wells have shallow production casing, which extends only 361 feet below the surface in some cases⁷⁵—a point *above* the deepest groundwater resources. Gas wells with shallow production casing and deep groundwater wells are not juxtaposed, but indicate the possibility that there are relatively small separations between water resources and fractured wells.

The EPA sampled water in four rounds of testing between March 2009 and April 2011.⁷⁶ These tests included two deep monitoring wells as well as shallow wells near evaporation pits and existing water wells for stock, domestic, and municipal use. A draft report was filed in late 2011.⁷⁷ This report indicated that chemicals from fracking fluids were found in groundwater. This was the “smoking gun” that environmentalists had been waiting for, and several groups wasted no time in advertising the draft findings.⁷⁸ Industry groups, including Encana, responded to the alleged link between the contamination and the wells fiercely.⁷⁹

The ensuing public debate led the United States Geological Survey (USGS), working with the Wyoming Department of

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72. The drilling of natural gas wells began in 1960. *Id.* Encana drilled forty-four new wells between 2004 and 2007, but no wells have been drilled since then. *Id.*
73. EPA DRAFT REPORT, *supra* note 70, at 2.
74. *Id.*
75. *Id.*
76. *Id.* at 5.
77. *Id.*
78. A summary of all responses is provided by Peter Folger. *See* FOLGER ET AL., *supra* note 65, at 13 nn.49–50, 14 nn.52–53.
79. *See, e.g., Six—Actually, Seven—Questions for EPA on Pavillion, ENERGY IN DEPTH* (Feb. 20, 2013, 9:17 AM), <http://www.energyindepth.org/six-questions-for-epa-on-pavillion> (questioning claims of contamination); Encana, *supra* note 71 (same).

Environmental Quality, to take additional groundwater samples from the EPA's wells for testing. The USGS report⁸⁰ was released in September of 2012 and discredited the central results regarding fracturing fluid contamination in the EPA draft report. The EPA backed off some of the conclusions in the draft report⁸¹ and delayed the comment deadline for the draft report well into 2013.⁸² The experience in Pavillion holds a number of lessons, most importantly that the standard of proof is high and that acquiring evidence is difficult.

CONCLUSION

In combination with other technologies, hydraulic fracturing has helped revolutionize the domestic oil and gas supply outlook in the United States. Although a precise accounting of the benefit-cost ratio is not feasible, the source of the gains starts with the massive increase in reservoir contact that properly designed and implemented fractures provide. This in turn increases initial production rates and the ultimate recovery of unconventional wells.

But fracking is still imperfectly understood, which provides both opportunities and risks. The opportunities for reducing the variance in well performance suggest that the technology can still be fine-tuned and productivity gains can be recognized. The environmental risks associated with an evolving technology are nontrivial. There has been particularly strong grassroots resistance to unconventional oil and gas development. That popular discontent has led to calls for increased regulatory oversight. Demonstrable and verified links between fracking and environmental harm are still lacking. The events in Pavillion, Wyoming, indicate that the burden of proof is quite high and that definitive evidence of harm will likely be required before regulations are created.

Given the widespread benefits of increased domestic oil and gas production and the bundle of technologies that have helped give rise to those gains, one might consider why the resistance has coalesced around fracking and not some other aspect of development. The most convincing answer to that question might be one of political convenience. In creating thousands of good-paying jobs, the industry does not offer very promising villains in the form of roughnecks and

80. PETER R. WRIGHT ET AL., U.S. GEOLOGICAL SURV., GROUNDWATER-QUALITY AND QUALITY-CONTROL DATA FOR TWO MONITORING WELLS NEAR PAVILLION, WYOMING, APRIL AND MAY 2012 (2012).

81. EPA SUMMARY, *supra* note 65.

82. Cassie J. Dallas, *EPA Extends Comment Period on Pavillion Groundwater Revised Report*, N. AM. SHALE BLOG (Jan. 16, 2013), <http://www.northamericashalebog.com/2013/01/16/u-s-epa-issues-updates-on-dimock-and-pavilion-sampling>.

other blue-collar beneficiaries. But the handful of corporations that have been the key to the propagation of hydraulic fracturing are more conspicuous and sufficiently anonymous to demonize. Halliburton makes a convenient foil.

A final thought about fracking provides some context for debate. A return to an earlier technology that was less productive and potentially more environmentally harmful is even less appealing than fracking. In 1969, a forty-three kiloton nuclear bomb was detonated underground near Rulison, Colorado, in an attempt to free trapped natural gas.⁸³ The explosion was not successful in freeing large amounts of gas, and what gas was freed was too radioactive to market. The area remains off-limits to drilling today due to radioactivity concerns, despite active drilling in the surrounding area.⁸⁴ Another failed experiment in 1973 in nearby Rio Blanco County, Colorado,⁸⁵ led energy firms to experiment again with hydraulic fracturing. It is no coincidence that some of the advances made in fracking were made in the same area of western Colorado. The unconventional resources are there, and the ingenuity of engineers will be constantly applied to unlock those valuable resources. Hopefully that ingenuity can be married to wisdom of other specialists to produce a workable regulatory framework for hydraulic fracturing and unconventional oil and gas development more broadly. If not, and fracking bans are more widely adopted, consideration may be needed for the appropriate regulatory framework for improved nuclear fracturing.

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83. U.S. DEP'T OF ENERGY, RULISON, COLORADO, SITE: FACT SHEET (2011).
84. The annulus around the site that is off limits has been reduced. Mark Jaffe, *Plans Moving Ahead for Drilling near Underground Atomic Blast*, DENVER POST, Dec. 24, 2009, http://www.denverpost.com/ci_14060298?IADID.
85. See generally Daniel Noonan, *Nuclear Bomb Test at Rio Blanco Site, CO*, WASH. NUCLEAR MUSEUM & EDUC. CENTER (Feb. 9, 2011), <http://toxipedia.org/display/wanmec/Nuclear+Bomb+Test+at+Rio+Blanco+Site,+CO>.



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