THE FRACKING REVOLUTION: A CASE STUDY IN POLICY LEVERS TO PROMOTE INNOVATION

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ABSTRACT

The first decade of the twenty-first century has witnessed a boom in oil and natural gas production that promises to turn the United States into a new form of "petrostate." This boom raises a number of important questions that scholars have begun to explore, including questions of risk governance, federalism, and export policy. Relatively neglected, however, have been questions of why this revolution occurred and what the story behind the revolution teaches about innovation theory and the usefulness of various innovation policy levers. By weaving together examination of infrastructure developments, government-sponsored research and development, intellectual property, rights in tangible assets, and tax and regulatory relief, this Article indicates how a blend of policy levers can support innovation and suggests how governments might use such levers to foment the next energy revolution, one that could move us toward a cleaner and more secure future.

Historical accounts of the oil and gas boom commonly focus on the risk-taking and persistence of George Mitchell, whose independent production company pioneered techniques of "slickwater" hydraulic fracturing ("fracking") in Texas' Barnett Shale. A richer account reveals a more complicated story: the fracking revolution in fact reflects the convergence of a wide range of technological advances, private investments, and government policies. Key lessons from this richer account include the need for patience in fostering game-changing technologies, the value of diversification in both the performers and the targets of innovative efforts, and the importance of physical and legal infrastructure that supports a diverse innovation ecosystem.

Significantly for theories of intellectual property, patents appear to have played an only modest and auxiliary role in the story behind the boom. The story thus highlights that, even in capital-intensive and highly competitive for-profit environments, intellectual property might play only a relatively humble role in promoting innovation. Particularly where complementary assets like land and mineral rights provide means to appropriate innovation's value, the fostering of a balanced environment of competition, coordination, and information exchange might properly take a front seat to aggressive deployment or enforcement of intellectual property.

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INTRODUCTION

Innovations in hydraulic fracturing and horizontal drilling (often collectively referred to as "fracking") have produced a revolution in natural gas extraction. The United States, the world leader in these technologies' development and exploitation, has suddenly returned to the role of energy-producing superpower.[3] Cheaper and more stably priced natural gas, commonly derived from underground shale formations, promises to provide a long-lasting boost to a flagging U.S. economy,[4] even aiding in a revival of U.S.-based manufacturing.[5] Both positive and negative spillover effects—economic, environmental, and political[6]—promise to run not only across the United States' continental breadth but around the globe.

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[3] *See U.S. Expected to be Largest Producer of Petroleum and Natural Gas Hydrocarbons in 2013*, ENERGY INFO. ADMIN., http://www.eia.gov/todayinenergy/detail.cfm?id=13251.

[4] *See* ENERGY INFO. ADMIN., AEO 2014 EARLY RELEASE OVERVIEW at 1 (2014), http://www.eia.gov/forecasts/aeo/er/pdf/0383er%282014%29.pdf ("Ongoing improvements in advanced technologies for crude oil and natural gas production continue to lift domestic supply and reshape the U.S. energy economy.").

[5] ALAN KRUPNICK ET AL., RESOURCES FOR THE FUTURE, SECTOR EFFECTS OF THE SHALE GAS REVOLUTION IN THE UNITED STATES 36-39 (2013), http://www.rff.org/RFF/Documents/RFF-DP-13-21.pdf (exploring the impacts of domestic shale gas production on the manufacturing sector and projecting that "[a]n expansion in the production capacity of ethylene will probably boost production in a wide variety of manufacturing industries . . . ."); American Chemistry Council, Shale Gas, Competitiveness, and New US Chemical Industry Investment: An Analysis Based on Announced Projects at 27 (2013), http://chemistrytoenergy.com/sites/chemistrytoenergy.com/files/shale-gas-full-study.pdf (noting that "renewed competitiveness from shale gas is already occurring," creating and estimated $2.2 billion in added value in 2012).

[6] For discussions of these effects, see, *inter alia*, the following sources: Cliff Frohlich et al., *The Dallas-Fort Worth Earthquake Sequence: October 2008 through May 2009*, 101 BULL. SEISMOLOGICAL SOC'Y AM. 327 (2011) (describing earthquakes caused by the disposal of liquid oil and gas wastes); Dept. of the Interior, Fish & Wildlife Service, 50 C.F.R. Part 17, Docket No. FWS-R5-ES-2012-0045, Endangered and Threatened Wildlife and Plants; Endangered Species Status for Diamond Darter, Final Rule, July 26, 2013, http://www.gpo.gov/fdsys/pkg/FR-2013-07-26/html/2013-17938.htm (describing a species in the Marcellus Shale area that has become endangered); Michelle L. Hladik et al., *Discharges of Produced Waters from Oil and Gas Extraction via Wastewater Treatment Plants Are Sources of Disinfection By-Products to Receiving Streams*, 466-477 SCI. OF THE TOTAL ENV'T 1085, 1092 (2014); TIMOTHY W. KELSEY, ET AL., PENN STATE EXTENSION, ECONOMIC IMPACTS OF MARCELLUS SHALE IN PENNSYLVANIA: EMPLOYMENT AND INCOME IN 2009 (2011), http://www.marcellus.psu.edu/resources/PDFs/Economic%20Impact%20of%20Marcellus%20Shale%202009.pdf (exploring positive economic benefits); Kenneth B. Medlock et al., Rice University Baker Institute, Shale Gas and U.S. National Security (2011), http://bakerinstitute.org/files/496/ (describing many positive economic and security-based

The fracking revolution thus represents a massive burst of innovation that could hold lessons for further technological development, including additional energy transformations. The revolution reflects a classic disruptive innovation, potentially the very kind of innovation that, assuming adequate containment of any negative side effects, government policy should most look to foster. Yet few scholars have explored why this innovation occurred, or how the story behind the fracking revolution comports with or departs from dominant innovation theory. This Article examines the public policies, economic forces, and private initiatives that helped produce the fracking revolution. The Article then draws from this examination lessons for the promotion of future innovation and for innovation theory generally.

This case-study approach to studying innovation seems particularly apt in light of current levels of understanding. Limits on our knowledge of the mechanics of innovation often render generalized theorizing and narrow econometric studies of relatively little use. Case studies of specific innovation trajectories can support and guide later theoretical and econometric efforts. The physicist Richard Feynman described "[o]bservation, reason, and experiment [as] mak[ing] up what we call the scientific method,"[7] and we believe it was not mere chance that Feynman listed observation first. As with careful recording of celestial motions in the early stages of the Scientific Revolution, careful observation of specific innovation trajectories might be among the best ways to move understanding forward.[8]

Why study fracking as a foundation for more nuanced innovation theory? Pharmaceutical, biotech, communications, and computer-related

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impacts); Brian C. Rahm & Susan J. Riha, *Toward Strategic Management of Shale Gas Development: Regional, Collective Impacts on Water Resources*, 17 ENVTL. SCI. & POLICY 12, 15 (2012) (describing water quality and quantity impacts); WILLISTON IMPACT STATEMENT 2012, http://www.willistondevelopment.com/usrimages/Williston_Impact_Statement.pdf (describing local infrastructural and service-based impacts as well as tax revenues); Hannah Wiseman, *Risk and Response in Fracturing Policy*, 84 U. COLO. L. REV. 729 (2013) (describing many of the impacts based on state enforcement of oil and gas regulations at unconventional well sites).

[7] RICHARD P. FEYNMAN, SIX EASY PIECES: ESSENTIAL PHYSICS EXPLAINED BY ITS MOST BRILLIANT TEACHER 24 (Robert B. Leighton & Matthew Sands eds., 1995) (emphasis omitted).

[8] *Id.* at 90 (describing how Tycho Brahe's careful observation of planetary trajectories laid the basis for Kepler's discovery of "some very beautiful and remarkable, but simple, laws"); *cf.* GERALD HOLTON & STEPHEN G. BRUSH, INTRODUCTION TO CONCEPTS AND THEMES IN PHYSICAL SCIENCE 38 (2d ed. 1985) (noting that Tycho Brahe "spen[t] nearly a lifetime in patient recording of planetary motion with unheard-of precision").

technologies have commonly provided the basis for modern debates about how innovation works. Given the social and political salience of these technologies, the attention devoted to these areas is understandable. But energy technologies seem a more than worthy addition to this common grouping. The energy sector has a long history of cutting-edge innovation, and innovations in energy technology have long undergirded innovation in much of the rest of the economy. The Industrial Revolution motored forward on the basis of, first, new technologies for harnessing wind and water,[9] and, second, even newer, interconnected technologies for extracting coal and harnessing steam.[10] Needless to say, the modern Information Revolution has relied on later advances in the production and harnessing of electrical energy.

In short, energy technologies are vitally important, and fracking has proven remarkably so. It also happens to have a fascinating origin story. A common quasi-myth is that fracking's commercial development is largely the tale of a single oil-industry entrepreneur, George Mitchell, who bucked conventional wisdom, risked millions, and persisted for years in efforts to make unconventional gas reserves commercially exploitable.[11] Indeed,

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[9] JOEL MOKYR, THE LEVER OF RICHES: TECHNOLOGICAL CREATIVITY AND ECONOMIC PROGRESS 34 (1990) (noting medieval advances in harnessing energy from wind and water).

[10] *Id.* at 85 (observing that "the first economically successful [steam] engine … was installed in a coal mine near Wolverhampton in 1712" and "solved drainage problems … in the deep coal mines in the north of England").

[11] *See* DANIEL YERGIN, THE QUEST: ENERGY, SECURITY, AND THE REMAKING OF THE MODERN WORLD 327 (2011) ("Mitchell's relentless commitment … would transform the North American natural gas market and shake expectations for the global gas market."); *America's Bounty: Gas Works*, ECONOMIST, July 14, 2012 ("[T]he biggest difference [in fracking's development] was down to the efforts of one man: George Mitchell, the boss of an oil-service company," who "spent ten years and $6m to crack the problem" even though "[e]veryone, he said, told him he was just wasting his time and money"); Jonathan D. Silver, *The Marcellus Boom/Origins: The Story of a Professor, a Gas Driller, and Wall Street*, PITT. POST-GAZETTE, Mar. 20, 2011 ("[I]n the early 1980s, Texas oilman George P. Mitchell pursued a fringe strategy—exploring the Barnett Shale."); *see also* GREGORY ZUCKERMAN, THE FRACKERS: THE OUTRAGEOUS INSIDE STORY OF THE NEW BILLIONAIRE WILDCATTERS 5 (2013) (asserting that "a small group of individuals made [a new age in U.S. oil and gas production] happen, against all odds," and crediting Mitchell, "who discovered a novel way to extract gas from shale formations" with "impact [that] eventually might even approach that of Henry Ford and Alexander Graham Bell"). *But see* Zhongmin Wang & Alan Krupnick, Resources for the Future, *A Retrospective Review of Shale Gas Development in the United States: What Led to the Boom?* at 3 (2013), http://www.rff.org/RFF/documents/RFF-DP-13-12.pdf (exploring in detail the many factors contributing to the technological innovations behind the shale gas boom and largely agreeing with the "myth" that "it was the private entrepreneurship from Mitchell Energy & Development) . . . that played the primary role in developing the Barnett play in Texas").

Mitchell deserves great credit both for unusual persistence and for his company's ultimate development of a "formula" for combining horizontal drilling and "slickwater" fracturing in a way that industry not only lauded but also adapted with awesome rapidity to shale and tight sandstone formations around the United States.[12]

But even a Mitchell-centric view of fracking's development acknowledges that there were other factors that contributed critically to the natural gas boom. A great number of these related to physical, legal, and economic infrastructure that provided a foundation upon which unconventional natural gas pioneers could hope to successfully operate. Important aspects of this foundation were "a deep and liquid gas market that allowed the risks of drilling to be hedged, ready access to capital, America's home-grown oil industry," and "the liberalization of access to existing pipelines by third parties" that raised the prospects of independent producers such as Mitchell Energy and Development.[13] Arguably even more fundamental were well-established property systems for leases of land and mineral rights, crucial complementary assets to natural-gas-resource development that helped drive much risk taking and innovation.[14]

Further vital preconditions for Mitchell's successful "fracking synthesis" included multiple lines of innovation that sometimes reached decades into the past. Such lines could include "beyond the wellhead" innovations that, for example, facilitated the construction and operation of interstate pipelines[15] or improved capacities to characterize and map underground shales.[16] The "at the wellhead" technologies of horizontal

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[12] Earlier fracturing techniques used large volumes of water and sand as "proppant" to prop open fractures were formed, or large volumes of gels to "cross link" fluids. Slickwater fracturing combined several previous techniques, using more water, different chemicals, and moderate amounts of sand, although even the slickwater technique varies among formations. *See* Hong Sun et al., *A Nondamaging Friction Reducer for Slickwater Frac Applications*, SOC'Y PETROLEUM ENGINEERS 139480 (2011) ("Slickwater fracturing, different from fracturing using cross-linked fluids, has been developed and used in tight gas sand reservoirs since successful operations in the Cotton Valley Sand in East Texas in 1997."); Wiseman, *supra* note 6, at 744 n. 60 (describing older gel-based and high sand volume techniques and providing sources).

[13] *America's Bounty*, ECONOMIST, *supra* note 11.

[14] [14] *See* Wang & Krupnick, *supra* note 11.

[15] *See infra* text accompanying notes __.

[16] *See, e.g.*, Quinton R. Passey, et al., *From Oil Prone Source Rock to Gas-Producing Shale Reservoir – Geologic and Petrophysical Characterization of Unconventional Shale-Gas Reservoirs*, SOC'Y PETROLEUM ENGINEERS 131350 (2010) (noting that geochemical and petrophysical techniques" used to "characterize organic-matter-rich source rocks" were for the most part "developed to characterize thermally mature source rocks" that were conventional and unlike shales," the same techniques can be applied, sometimes with

drilling and hydraulic fracturing themselves emerged from an array of sub-innovations that preceded Mitchell. Some, such as chemical formulations[17] and drilling equipment,[18] reflected relatively large bursts of progress in multiple industrial sectors. Others built upon years of incremental change.

Meanwhile, private forces for innovation benefited from public aid. In the 1970s and 1980s, the U.S. Bureau of Mines (later part of the Energy Research and Development Administration[19]) and Department of Energy "spent hundreds of millions"[20] on research that helped both point and pave the way for Mitchell's ultimate success.[21] Moreover, public support extended far beyond early R&D. Fracking has long benefited from federal-private research partnerships[22] as well as both tax[23] and regulatory[24] relief,

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modification, to the shale-gas class of unconventional reservoirs" and describing some of the modifications required).

[17] In the 1970s, energy companies "'borrowed' from the plastic explosives industry" chemical agents that improved fracturing solutions. Carl T. Montgomery & Michael B. Smith, *Hydraulic Fracturing: History of An Enduring Technology*, J. PETROLEUM TECH. 26, 28 (2010), http://www.spe.org/jpt/print/archives/2010/12/10Hydraulic.pdf.

[18] The development of special motors allowed companies to drill long horizontal wellbores into the most productive portions of a formation. U.S. DEPT. OF ENERGY, NATL. ENERGY TECH. LAB., SHALE GAS: APPLYING TECHNOLOGY TO SOLVE AMERICA'S CHALLENGES 3 (2011), *available at* http://www.netl.doe.gov/technologies/oil-gas/publications/brochures/Shale_Gas_March_2011.pdf.

[19] For a discussion of consolidations in the 1970s, after which the DOE oversaw all energy R&D, see Wang & Krupnick, *supra* note 11, at 7-8.

[20] Alex Trembath, Letter to the Editor, *A Joint Effort*, ECONOMIST, Aug. 4, 2012

[21] Alex Trembath, *History of the Shale Gas Revolution*, Dec. 14, 2011, *available at* http://thebreakthrough.org/archive/history_of_the_shale_gas_revolution (last visited on Nov. 27, 2012) (discussing how the Bureau of Mines' Morgantown Energy Research Center "launched the Eastern Gas Shales Project" and "contracted with dozens of universities and private companies to demonstrate gas recovery from shale formations and other unconventional gas reserves"); *id.* (noting that DOE's role in the first demonstrations of "massive hydraulic fracturing" and "a multi-stage directional fracture"). *See also, c.f.*, Wang & Krupnick, *supra* note 11, at 3 (concluding that "some of the key technology innovations resulted from government research and development (R&D) programs and private entrepreneurship" but that "some of the key technologies . . . were largely developed by the oil industry"); *id*. (noting, in particular, the role of government research in developing early "key technologies" in the Michigan and Appalachian Basins in the 1970s when "US gas producers were small").

[22] Trembath, *supra* note 21 ("In 1991, Mitchell partnered with DOE and the federally funded Gas Research Institute (GRI) to develop tools that would effectively fragment formations in the Barnett Shale.").

[23] Trembath, Letter, *supra* note 20 (noting that the U.S. government offered a "$10 billion production tax credit for unconventional gas between 1980 and 2002").

[24] David B. Spence, *Federalism, Regulatory Lags, and the Political Economy of Energy Production*, 161 U. PA. L. REV. 431, 449 (2013) ("Fracking operations enjoy some exemptions from federal environmental regulation."); Michael Burger, Response, *Fracking*

three different means for effectively subsidizing this technology relative to other commercial ventures. Perhaps most (in)famously, the Energy Policy Act of 2005 created the so-called "Halliburton Loophole"[25] that exempted all chemicals used in fracking except diesel fuel from federal regulation as an "underground injection."[26] This ensured that a potentially large permitting hurdle would not apply to the oil and gas industry, although it simultaneously generated environmental concern because "frackers" were thereby generally exempted from a need to demonstrate that their injections would not endanger underground sources of drinking water.[27] Meanwhile, trade-secret protection has enabled companies to invoke proprietary rights as a means not only to stay ahead of competitors but also to avoid disclosure of fracking chemicals to regulators and the public[28]—another factor that arguably supports innovation yet might endanger other public interests.[29]

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and Federalism Choice, 161 U. PA. L. REV. ONLINE 150, 157 (2013) ("Due to a toxic blend of agency capture, flawed research, and shortsighted administrative decisions, the federal government's leadership in fracking regulation has been paralyzed.").

[25] Barbara Warner & Jennifer Shapiro, *Fractured, Fragmented Federalism: A Study in Fracking Regulatory Policy*, PUBLIUS: THE JOURNAL OF FEDERALISM, Apr. 18, 2013, at 1, 6.

[26] Hannah Wiseman, *Untested Waters: The Rise of Hydraulic Fracturing in Oil and Gas Production and the Need to Revisit Regulation*, 20 FORDHAM ENVTL. L. REV. 115, 145 (2009) (discussing and quoting the Energy Policy Act of 2005); 42 U.S.C. § 300h (d)(1) (codifying the exemption).

[27] 42 U.S.C. § 300h.

[28] Warner & Shapiro, *supra* note 25, at 13 (noting that various states limit disclosure requirements for fracking chemicals "that companies deem proprietary"); Hannah J. Wiseman, *Trade Secrets, Disclosure, and Dissent in a Fracturing Revolution*, 111 COLUM. L. REV. SIDEBAR 1 (2011) (describing federal and state trade secret allowances).

[29] Many public comments on proposed state and regional fracturing regulations—even rules unrelated to chemical disclosure—have focused on concerns about the chemicals used in hydraulic fracturing and the lack of trade secret disclosure. *See, e.g.*, Railroad Comm'n of Tex., 16 TAC Chapter 3—Oil and Gas Division at 14, Dec. 13, 2011, http://www.rrc.state.tx.us/rules/signed-adopt-3-29-Dec13-2011.PDF (in finalizing fracturing chemical rules and responding to public comments, noting that a commenter argued that "disclosure of proprietary chemicals should be made to the Commission (with a non-disclosure agreement)", that the Environmental Defense Fund requested an expanded definition of emergency responders who could receive trade secret information, and that the City of Dallas requested that the identity of trade secret chemicals be disclosed to emergency responders and other health professionals when chemicals spilled on the ground); Dept. of Natural Resources Conservation Montana Bd. of Oil and Gas, Hydraulic Fracturing Rulemaking, Written and Emailed Public Comments at 1, 16 (2011), http://bogc.dnrc.mt.gov/PDF/CombinedComments.pdf (showing comments such as "I want to know what is in the chemicals as they will end up in my food and water" and "[w]ell stimulation fluids should be disclosed to the public to protect water supplies and allow land owners a reasonable opportunity to a) object, and b) monitor water quality").

Notably, patents appear to have been only bit players in the basic story behind the fracking revolution. Somewhat ironically in light of Edmund Kitch's use of resource-extraction rights to motivate his theory of "pioneer patents,"[30] "during the late 1990s and early 2000s neither Mitchell [Energy] nor [its ultimate acquirer,] Devon [Energy,] pursued patent protection for their respective innovations in slickwater hydraulic fracturing and horizontal drilling."[31] Far from holding fracking's further development back, such restraint in patenting might have helped enable the recent natural gas "gold rush," "with companies racing to capitalize on innovative, yet unpatented technologies in other geographies."[32] Although patents might have played a nontrivial role in the technology buildup that enabled Mitchell's turn-of-the-millennium breakthrough, their marginalization at this critical point demonstrates how, under appropriate circumstances, innovation's development and diffusion can proceed apace—perhaps even at a faster pace—without great resort to intellectual property. Quite generally, the story indicates how intellectual property and other relatively direct policy levers such as tax and regulatory relief can sometimes play no more than a supporting role in a specific course of technological development. Although the carrots that these policy levers offer can help entice would-be innovators and can even help support them on the march toward a technological goal,[33] the nature of the landscape over which would-be innovators must march—as shaped and informed by governments, markets, and cultures of information accumulation and exchange—might be at least as important.

This Article's exploration of the how and why of technological developments behind the shale gas boom proceeds as follows. Part I introduces the wellhead technologies that drove the boom, and Part II explores factors beyond the wellhead—national markets and infrastructure that supported innovation in horizontal drilling and hydraulic fracturing. Part III describes various sub-innovations that converged to generate the "Mitchell synthesis" of techniques of horizontal drilling and fracturing. Continuing the discussion of factors supporting innovation at the wellhead,

[30] Edmund W. Kitch, *The Nature and Function of the Patent System*, 20 J.L. & ECON. 265, 266 (1977).
[31] Daniel R. Cahoy, Joel Gehman & Zhen Lei, *Fracking Patents: The Emergence of Patents as Information Tools in Shale Drilling*, 19 MICH. TELECOMM. & TECH. L. REV. 279, 291 (2013).
[32] *Id.* at 292-93.
[33] *See generally* Daniel J. Hemel & Lisa Larrimore Ouellette, *Beyond the Patents-Prizes Debate*, 92 TEX. L. REV. 303, 311-12 (2013) (describing how prizes, grants, exclusive rights such as intellectual property rights, and tax relief can affect a would-be innovator's incentives).

Part IV describes the government role in advancing hydraulic fracturing and horizontal drilling through such policy mechanisms as research partnerships and regulatory and tax-based support. Part V discusses roles of intellectual property and information exchange in the technological developments leading to the shale gas boom, analyzing in particular the role—or relative non-role—that patents played in this story of innovation. Part VI considers how the overall story might inform efforts to advance innovation elsewhere, including in other portions of the U.S. energy sector.

Because federal and state governments implemented a smorgasbord of innovation-related policies—e.g., infrastructure development, R&D funding and partnerships, tax and regulatory relief, laws protecting complementary assets, and laws offering intellectual property rights—it seems folly to think one can tease out of this single case study any definitive, universal truths about how a wealth of apparent policy levers can be best used to promote innovation. Indeed, even beyond the difficulty of disentangling the effects of different policy levers in this individual case, there is the problem that the single case study can shed little, if any, light on the relative merits of devoting social resources to development of technologies for natural gas extraction as opposed to devoting those resources to any of a number of possible alternative endeavors—such as enjoyment of leisure or, more in the spirit of this article, development of technologies for wind energy, solar energy, or energy conservation.

Nonetheless, the case study provides insight into the multi-layered complexity of some innovation processes and the likely value of a well-diversified public and private response to innovation's support. The story suggests that government can play key roles through the patient development of infrastructure, fostering of information exchange, and even relatively modest but well-targeted investments in R&D. To the extent private parties are expected to make large capital investments, prospects for adequate rewards might be necessary,[34] but the story shows how intellectual property rights can be relatively insignificant as a mechanism for reward and how supporting infrastructure such as pipelines and healthy national markets can be crucial. Such lessons do not provide a precise formula for innovation in the energy sector or other fields, but they can help guide the deployment of policy levers that might enable future technology revolutions.

[34] Amy Kapczynski & Talha Syed, *The Continuum of Excludability and the Limits of Patents*, 122 YALE L.J. 1900, 1908 (2013) ("Conventional economic actors will only produce a good when they can appropriate sufficient returns to recoup the capitalized costs of providing the good.").

I. A PRIMER ON THE SHALE GAS BOOM AND THE TECHNOLOGIES BEHIND IT

Hydraulic fracturing and horizontal drilling are now key factors in the exploitation of a great variety of fossil fuel resources. But this paper focuses on the most revolutionary field of their recent use—the extraction of natural gas from underground shale formations, which consist of "hard, concretelike" rock[35] formed by sediment and organic matter that accumulated in formerly marine environments.[36] This part discusses the United States' shale gas boom and the intricate combination of technological developments that lies behind it.

A. REVOLUTION IN U.S. SUPPLY OF NATURAL GAS

The remarkable nature of the recent growth of domestic unconventional gas production is underscored by comparing the current situation to that in the very first years of the twenty-first century. Already in 2001, a National Research Council report had declared past public support for shale gas production to have been a success.[37] In the mid-1970s, the Council reported, the United States had extracted about 70 billion cubic feet (70 Bcf) of natural gas from shale formations.[38] By 1998, that amount had risen by over a factor of five to 380 Bcf per year.[39] With natural gas production from the Barnett Shale expected to join that from the Eastern Gas Shales, shale gas production was expected to rise to 0.8 trillion cubic feet (0.8 Tcf, equivalent to 800 Bcf) by 2010 and to nearly 1 Tcf per year by 2020.[40] According to the Council, the federal government's Eastern Gas Shales Project of 1976 to 1992 had already generated benefits to industry of $705 million in 1999 dollars, and these benefits exceeded project expenditures of $148 million by a ratio of 4.8 to 1.[41] A much higher benefit-to-cost ratio would have resulted from taking into account "over $8 billion in consumer

[35] YERGIN, *supra* note 11, at 328.
[36] Passey et al., *supra* note 16, at 10 (describing how most shales "had their origin as organic-rich mud" and how the sediments in shale "could have been deposited in the marine environment, in lakes (lacustrine, or in associated swamps and mires along the margins of lakes or seas").
[37] NAT'L RESEARCH COUNCIL, ENERGY RESEARCH AT DOE: WAS IT WORTH IT? ENERGY EFFICIENCY AND FOSSIL ENERGY RESEARCH 1978 TO 2000, at 201 (2001) ("[I]ncentives through tax credits, combined with optimum deployment of advanced technology, served to revive a domestic gas province in decline.").
[38] *Id.*
[39] *Id.*
[40] *Id.*
[41] *Id.*

savings due to lower gas prices."[42] Given such figures, the Council had good reason to conclude that the past quarter century's fivefold increase in shale gas production and the future promise of a nearly threefold increase over the next couple decades were cause for celebration.[43]

Wonder then at how we should react to what actually occurred. By 2007, six years after the Council's report and thirteen years before annual shale gas production had been expected to "approach 1 Tcf,"[44] the United States extracted nearly 2 Tcf of shale gas.[45] In the past decade and a half, growth in shale gas production has been more than exponential. As noted above, shale gas production approximately quintupled in the more than twenty years from the mid-1970s to the late 1990s.[46] If the growth in shale gas production were exponential, production would have taken another twenty years or so to rise by another factor of five.[47] But in half that time—the ten years from 1998 to 2007—shale gas production more than quintupled again, rising from nearly 400 Bcf to nearly 2 Tcf.[48] Within a mere five additional years, United States' shale gas production had quintupled a third time. Production in 2012 amounted to more than 10 Tcf,[49] more than five times the production level in 2007 and about ten times the amount that the National Research Council had projected for 2020.[50] From 2000 to 2012, shale gas had gone from supplying only about 2% of the United States natural gas to supplying well over one third.[51] As Daniel Yergin put it, "[p]erennial shortage gave way to substantial surplus."[52] The

[42] *Id.*
[43] In 2002, another set of commentators reacting to shale gas production levels of just under 4,500 Bcf per year were similarly impressed. Vello A. Kuuskraa & Hugh D. Guthrie, *Translating Lessons Learned from Unconventional Natural Gas R&D to Geologic Sequestration Technology*, 2 J. ENERGY & ENVTL. RESEARCH 75, 81 (2002) (citing 1999 production level of 0.37 Tcf). As they observed, "[a] poorly-understood, high-cost energy resource, one that the U.S. Geological Survey had not even included in its national appraisals of future gas resources (until their most recent 1995 assessment) is now providing major volumes of annual gas supplies." *Id.* at 80.
[44] NAT'L RESEARCH COUNCIL, *supra* note 37, at 201.
[45] U.S. Energy Information Administration, U.S. Natural Gas Withdrawals from Shale Gas (Million Cubic Feet), http://www.eia.gov/dnav/ng/hist/ngm_epg0_fgs_nus_mmcfa.htm (visited Feb. 16, 2014) [hereinafter "U.S. Natural Gas Withdrawals"].
[46] *See supra* text accompanying notes __.
[47] WILLIAM J. BAUMOL & ALAN S. BLINDER, ECONOMICS: PRINCIPLES AND POLICY 820 (5th ed. 1991) ("Exponential growth is growth at a constant percentage rate." (emphasis omitted)).
[48] *Compare supra* text accompanying notes __ to *supra* text accompanying notes __.
[49] U.S. Natural Gas Withdrawals, *supra* note 45.
[50] *See supra* text accompanying notes __.
[51] YERGIN, *supra* note 11, at 331.
[52] *Id.*

United States now looks forward to becoming a net exporter of natural gas within a decade.[53]

The world is still absorbing the significance of this natural gas revolution, one that has helped turn the United States into an unexpected, technology-driven "petrostate" of a type never seen before.[54] The "shale gale"[55] of the past decade has generated a huge range of straightforward economic benefits, including improved GDP and balance-of-payments numbers, increased employment and tax revenues,[56] and "on the order of $100 billion of gains to consumers each year."[57] Low natural gas prices have helped revitalize U.S. manufacturing, particularly in the natural-gas-dependent petrochemicals industry.[58] Reduced U.S. and foreign dependence on energy-rich states that have often been either unstable or hostile to U.S. interests could shake up geopolitics for decades to come.[59] Finally, although the environmental record of "fracking" is far from unblemished, ample supplies of natural gas offer the possibility of significant environmental benefits. Natural gas is a much cleaner-burning fuel than coal and has already contributed to recent declines in the United

[53] JASON BURWEN & JANE FLEGAL, UNCONVENTIONAL GAS EXPLORATION & PRODUCTION, *in* AMERICAN ENERGY INNOVATION COUNCIL, CASE STUDIES ON THE GOVERNMENT'S ROLE IN ENERGY TECHNOLOGY INNOVATION 7 (2013) ("The US is now expected to become a net exporter of natural gas in the next decade.").

[54] *The Petrostate of America*, ECONOMIST, Feb. 15, 2014, at __ (noting that the United States' "'fracking' revolution" "owes less to geological luck than enterprise, ready finance and dazzling technology").

[55] YERGIN, *supra* note 11, at 331 (internal quotation marks omitted).

[56] *See* Thomas W. Merrill & David M. Schizer, *The Shale Oil and Gas Revolution, Hydraulic Fracturing, and Water Contamination: A Regulatory Strategy* 8-11 (2013) (reporting on combined contributions of unconventional fossil fuel resources to U.S. economic figures), *available at* [SSRN address].

[57] BURWEN & FLEGAL, *supra* note 53, at 7.

[58] *See* American Chemistry Council, Shale Gas and New Petrochemicals Investment: Benefits for the Economy, Jobs, and US Manufacturing (2011), http://chemistrytoenergy.com/sites/chemistrytoenergy.com/files/ACC-Shale-Report.pdf, Merrill & Schizer, *supra* note 56, at 9-10.

[59] *See* Merrill & Schizer, *supra* note 56, at 11-12 (suggesting that U.S. natural gas could reduce European dependence on Iran and Russia, as well as "enabl[ing] us to cut our defense budget"); *Petrostate*, *supra* note 54, at __ ("A world in which the leading petrostate is a liberal democracy has much to recommend it."). *But see* Baker Energy Institute, Shell Distinguished Lecture Series, World Energy Outlook, Fatih Birol, February 20, 2014 lecture, https://bakerinstitute.org/videos/uished-lecture-series-world-energy-outlook/ (noting that U.S. production likely will not continue at this pace beyond several decades and that middle eastern resources will continue to be very important).

States' greenhouse gas emissions.[60] In a post-Great-Recession world highly concerned with promoting economic growth, there is hope that natural gas could act as a "bridge fuel," enabling relatively painless reductions in near-term greenhouse gas emissions while the world works toward greater reliance on non-fossil fuels.[61]

B. A WEB OF TECHNOLOGIES BEHIND THE BOOM

Multiple new technologies undergird the shale gas boom, and the most prominent of these are hydraulic fracturing—specifically slickwater fracturing—and horizontal drilling. In a sense, both are relatively old technologies. Hydraulic fracturing to increase fuel extraction is commonly traced back to 1947,[62] and a horizontal well existed at least as early as 1929.[63] But the combination and enhancement of these techniques by a host of improvements and ancillary technologies have yielded results that are qualitatively new.

At base, hydraulic fracturing—commonly known as "fracking"—is a process of pumping large amounts of liquid into a wellbore and selected areas of surrounding rock, with the liquid being pumped at a high enough pressure that the rock fractures.[64] In a natural-gas-bearing shale formation, the cracking of the hard but slightly porous rock helps expose surface area of the shale[65] and frees natural gas trapped within the shale, after which the gas travels through the wellbore to the surface, where it is collected,

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[60] *See* Energy Info. Admin., Natural Gas Issues and Trends 1998 at 52-53 (comparing emissions of nitrogen oxides, sulfur dioxide, particulates, carbon monoxide, and hydrocarbons from natural gas and coal and noting much lower emissions from natural gas); Spence, *supra* note 24, at 440-441 (citing these data and emphasizing the cleaner-burning qualities of gas).,

[61] J. Rothstein, Hydrogen and Fossil Fuels, 20 INT'L J. HYDROGEN ENERGY 283, 284 (1993); CTR. FOR AM. PROGRESS, NATURAL GAS: A BRIDGE FUEL FOR THE 21ST CENTURY, available at http:// www.americanprogress.org/issues/2009/08/bridge_fuel.html (last visited Feb. 10, 2010); Merrill & Schizer, *supra* note 56, at 12-13; Hannah Wiseman, *Regulatory Adaptation in Fractured Appalachia*, 21 VILL. ENVTL. L. J. 229, 231-232 (2010).

[62] Montgomery & Smith, *supra* note 17, at 26, 27 ("The first experimental treatment to 'Hydrafrac' a well for stimulation was performed in … Kansas, in 1947 ….").

[63] BURWEN & FLEGAL, *supra* note 53, at 3.

[64] See BURWEN & FLEGAL, *supra* note 53, at 2; CHIANG H. YEW, MECHANICS OF HYDRAULIC FRACTURING 1 (1997) ("This fluid pressure creates a fracture extending into the rock medium which contains oil or gas."). .

[65] *See* P. Kaufman & G.S. Penny, *Critical Evaluations of Additives Used in Shale Slickwater Fracs*, SPE 119900, at 1 (2008) (noting that horizontal wells are used to "create as much contact with the reservoir as possible").

processed, and transported, typically by pipeline.[66] To enhance the effectiveness of fracking, the liquid pumped into the rock is mixed with chemicals and one or more forms of "proppant," commonly sand.[67] Proppant particles are trapped in cracks generated by fracking and help "prop" them open—facilitating the continued flow of gas through the fractures by preventing the cracks from closing once the fracking liquid is absorbed into the shale or flows back out of the well.[68]

The nature of the fracking fluid and proppant is generally tailored to the particular geological formation being fracked.[69] For the types of shale gas formations of concern here, the fracking mixture tends to be about 98% to 99% or more water and sand, with the remainder consisting of any of a number of substances—for example, "friction reducing" agents such as polyacrylamides, biocides such as methanol to kill hydrogen sulfide-producing bacteria, "scale inhibitors" such as hydrochloric acid, surfactants such as butanol, and various other materials such as guar gum, borate salts, and isopropanol that can help optimize any of a variety of fracking fluid properties, such as thickness, viscosity, and ability to carry and release proppant.[70] Proppants can also be varied—for example, in terms of grain

[66] *See* C. CLARK ET AL., ARGONNE NATL. LABORATORY, HYDRAULIC FRACTURING AND SHALE GAS PRODUCTION at 3 (2013), http://www.afdc.energy.gov/uploads/publication/anl_hydraulic_fracturing.pdf (noting the reduction in pressure following fracturing, after which fluid (and later gas) flows out of the well, and noting that propped fractures create "a pathway for natural gas to flow back to the well").

[67] Montgomery & Smith, *supra* note 17, at 28.

[68] *See* BURWEN & FLEGAL, *supra* note 53, at 2; Mass. Inst. Technology, The Future of Natural Gas, Supplementary Paper SP 23 at 11, Role of Technology in Unconventional Gas Resources, http://mitei.mit.edu/system/files/Supplementary_Paper_SP_2_3_Unconventional_Technology.pdf; Yew, *supra* note 64, at 61. .

[69] *See* ANTHONY ANDREWS ET AL., CONG. RESEARCH SERV., R40894, UNCONVENTIONAL GAS SHALES: DEVELOPMENT, TECHNOLOGY, AND POLICY ISSUES 24 (2009) ("It is important to note that the service companies adjust the proportion of frac fluid additives to the unique conditions of each well."); JOHN H. GRAVES, FRACKING: AMERICA'S ALTERNATIVE ENERGY REVOLUTION 100-02 (2012) (noting that "[s]lick water is most commonly used in deep holes" and "[a]cid fracing … is used where the rock is susceptible to the etching of an acid wash"—for example, in a limestone or dolomite formation); Kaufman & Penny, *supra* note 65, at 1 (noting that "the selection of the fluid and additives" is "based upon the mineralogy").

[70] Graves, *supra* note 69, at 100-01 (describing "slick water" fracking fluids); Kaufman & Penny, *supra* note 65 (describing the additives and their purposes); N.Y. DEPT. OF ENVTL. CONSERVATION, REVISED DRAFT SUPPLEMENTAL GENERIC ENVTL. IMPACT STATEMENT at 5-4 to 5-48 (2011), http://www.dec.ny.gov/docs/materials_minerals_pdf/rdsgeisch50911.pdf (describing the typical percentage of chemicals by volume and listing the chemicals used); Jo Melville,

size, shape, coating, or source.[71] Some form of sand remains the dominant choice, but at one time or another fracturing service companies have tried a host of alternatives, including "plastic pellets, steel shot, Indian glass beads, aluminum pellets, high-strength glass beads, rounded nut shells, resin-coated sands, sintered bauxite, and fused zirconium."[72]

Such broad experimentation reflects the trial-and-error approach through which fracking has commonly developed—an approach that at least partly reflects difficulties in modeling the high-pressure dynamics of "sand-infused liquids" and their interactions with rock formations that can be more than a mile underground.[73] Computer programs have been used to plan or simulate fracking operations since the mid-1960s,[74] but they have failed to remove all elements of personal skill and luck from the process.[75]

In any event, fracking itself has not necessarily proven adequate to make shale gas production economically viable. Even with fracking, traditional vertical wells might not stimulate release of enough natural gas to justify their cost. Gas is commonly trapped at low densities throughout large areas of a shale and is often found in the greatest quantities in a small layer of the formation—sometimes within a portion of the shale that is less than one meter thick.[76] To optimize gas recovery, another technology has frequently been necessary: effective "directional drilling" in which oil and gas companies drill a well vertically to the formation that they are targeting, then slant the drill bit and drill laterally through the formation, sometimes for several miles.[77] This horizontal drilling exposes more surface area in the formation, as do the fractures that later emanate from this lateral wellbore, thus allowing more oil and gas to flow from the shale [78] Although

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Fracking: An Industry Under Pressure, 18 BERKELEY SCI. J. 22, 25 (2013) ("Modern fracking fluid consists on average of 99.5% freshwater and sand and a mere 0.5% additives.").

[71] GRAVES, *supra* note 69, at 102-03; *id.* at 106 ("The choice of sand type, its source, and its composition varies with each wellbore.").

[72] Montgomery & Smith, *supra* note 17, at 28.

[73] *See, e.g.*, GRAVES, *supra* note 69, at 107 ("The modeling of the fluid dynamics of sand-infused liquids is an ongoing aspect of deep research in frac tech.").

[74] Montgomery & Smith, *supra* note 17, at 31-32.

[75] GRAVES, *supra* note 69, at 103 ("Each choice [of fracking materials] depends on the engineering of the hole, the rock below, the skill and function of the men and equipment—and a goodly dose of luck.").

[76] Passey et al., *supra* note 16, at 2 (noting that "the vertical variability in organic richness can vary on relatively short vertical scales (often much less than 1 meter . . . .)).

[77] Halliburton, U.S. Shale Gas: An Unconventional Resource. Unconventional Challenges at 3 (noting that a "typical lateral" in the Barnett shale is "2,500 feet to 3,000 feet").

[78] ENERGY INFO. ADMIN., DRILLING SIDEWAYS—A REVIEW OF HORIZONTAL WELL TECHNOLOGY AND ITS DOMESTIC APPLICATION at 7 (1993); *see also* YERGIN, *supra* note

horizontal wells might cost, say, twice as much as a traditional vertical well, they can also be three times as productive, thereby increasing the overall benefit-to-cost ratio substantially.[79]

The rationale for drilling horizontally through shale formations was probably never hard to grasp. Developing the drilling and drill-monitoring technologies necessary to do it efficiently was the hard part. Prior to the 1980s, available technologies were crude. "Early directional drilling involved placing a steel wedge downhole (whipstock) that deflected the drill toward the desired target."[80] A great breakthrough came in the 1980s with the introduction of the "steerable downhole motor."[81] The 1990s witnessed further significant improvement through the development of "rotary steerable systems" that could be redirected without having to interrupt drilling by stopping rotation of the drill string.[82] Finally, the development of "measurement while drilling" technology, first commercialized in 1978, enabled real-time downhole measurement of parameters "such as position, temperature, pressure and porosity," thereby facilitating better directional control and generally more efficient and safer drilling, with the result being an even more favorable expected benefit-to-cost ratio.[83]

By this point, the reader might have begun to appreciate the complex and interlocking nature of the web of technological developments that underlie the shale gas boom. But any such appreciation is only a beginning. The list of important developments relating to shale gas extraction is not close to exhaustion. Additional innovations included (1) 3D seismic imaging techniques to locate the most abundant areas of gas underground, techniques that draw on technology developed to track submarines;[84]

11, at 330 ("Advances in controls and measurement allowed operators to drill down to a certain depth, and then drill at an angle or even sideways. This would expose much more of the reservoir, permitting much greater recovery of gas (or oil) from a reservoir.").

[79] G. Waters et al., *Use of Horizontal Well Image Tools to Optimize Barnett Shale Reservoir Exploitation*, SPE 103202, at 2 (2006) (observing that Devon Energy's experience in drilling "over 50 horizontal wells" in 2002 and 2003 "indicated that compared to vertical wells, the horizontals would have about three times the [estimated ultimate recovery] for twice the well cost").

[80] ANDREWS ET AL., *supra* note 69, at 19.

[81] Sara Pratt, *A Fresh Angle on Oil Drilling*, GEOTIMES, Mar. 2004, at __.

[82] ANDREWS ET AL., *supra* note 69, at 19.

[83] John E. Fontenot, *Measurement While Drilling—A New Tool*, J. PETROLEUM TECH., Feb. 1986, at 128, 128; *see also* Pratt, *supra* note 81, at __.

[84] Wang & Krupnick, *supra* note 11, at 13; Kevin Begos, Fracking Developed with Decades of Government Investment, Huffington Post, Sept. 23, 2012 ("[T]echnology created to track sounds of Russian submarines during the Cold War was repurposed to help the industry use sound to get a 3-D picture of shale deposits and track exactly where a drill

(2) "microseismic fracturing mapping," which reveals the "height, length, orientation, and other attributes of induced fractures" and allows an assessment of the effectiveness of the fracturing job;[85] (3) polycrystalline drill bits with artificial diamond surfaces[86] that are particularly well suited to drilling hard rock;[87] and (4) replacement of rigid well pipe with "flexible coiled tubing, continuously unreeled with a giant spool," a technology that eliminates the need to interrupt drilling while new "sections of pipe are screwed together and added to the rigid drill string."[88] Given the host of cutting-edge technologies involved, it is no wonder that modern oilfields have been compared to "high-tech factories."[89]

II. INNOVATION BEYOND THE WELLHEAD: INFRASTRUCTURE AND MARKETS

Despite the shale gas boom's multifarious technological backdrop, its trigger is often described as the work of a single man. After expending millions of dollars over a time period of nearly two decades,[90] the entrepreneurial George Mitchell ultimately deployed a combination of horizontal drilling and hydraulic fracturing technologies in the Barnett Shale of North Texas to produce surprising quantities of oil and gas relative to cost, thus jumpstarting the fracturing boom.[91]

This story is largely true. Mitchell was an innovator of remarkable persistence, and he drew attention to the potential for shale gas production and the use of two distinct techniques that had been deployed piecemeal over time. After years of failed trial and error, he and his independent

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bit was, thousands of feet underground."), *available at* http://www.huffingtonpost.com/2012/09/23/fracking-developed-government_n_1907178.html (visited on Feb. 4, 2014).

[85] Wang & Krupnick, *supra* note 11, at 14.

[86] MICHAEL P. GALLAHER, ALBERT N. LINK & ALAN O'CONNOR, PUBLIC INVESTMENTS IN ENERGY TECHNOLOGY 97 (2012).

[87] BURWEN & FLEGAL, *supra* note 53, at 6.

[88] Pratt, *supra* note 81, at __.

[89] *Petrostate*, *supra* note 54, at __.

[90] See G. Waters et al., *supra* note 79, at 1 ("Development of the Barnett Shale in the Fort Worth basin began in 1981 with the drilling of the Mitchell Energy C.W. Slay #1.").

[91] *See* DAN B. STEWARD, THE BARNETT SHALE PLAY, PHOENIX FOR THE FORT WORTH BASIN: A HISTORY 124-28 (2007) (recounting how the results from 1998 "light sand" fracturing in the Barnett Shale "changed [Mitchell Energy] and the industry's attitudes about the Barnett" and "basically started a leasing and drilling boom in southwest Denton and northwest Tarrant counties"); *id.* at 159-61 (noting that Mitchell Energy's "engineers were very encouraged with the results" of limited horizontal-well testing and that "Devon would take Mitchell's experience and turn horizontal drilling into a tool for major Barnett expansion").

production company, Mitchell Energy and Development, succeeded in "cracking the Barnett's code"[92] through a technique of slickwater fracturing that used formulas for fracking fluids remarkable for their relative simplicity.[93] When natural gas prices rose in the early 2000s, his example, which culminated in the sale of Mitchell Energy to Devon Energy for $3.5 billion in 2002,[94] became irresistible.[95]

Mitchell himself would likely have disclaimed this tale's simplicity. He actively sought and used collaborators, including federal government collaborators, in his developmental efforts, and he applied for and received federal incentive pricing for gas from the Barnett Shale, although this likely did not substantially affect project financing.[96] And the simplest version of the story misses a variety of other factors, many rooted in government support for innovation, that were essential drivers of the shale gas boom. The first innovation drivers ignored are changing national trends that were reshaping potential markets for natural gas even as techniques of horizontal drilling and hydraulic fracturing were maturing. These included government-backed incentives for the construction of interstate gas pipelines, the introduction of open access to pipelines, and the emergence of national markets in oil and gas. A combination of industry-wide initiatives and government policies supported these developments.

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[92] YERGIN, *supra* note 11, at 329.

[93] Jonathan D. Silver, *The Marcellus Boom/Origins: the Story of a Professor, a Gas Driller and Wall Street*, PITT. POST-GAZETTE, Mar. 20, 2011, at __ ("Instead of exotic formulas for hydraulic fracturing fluids used elsewhere, such as in North Sea fields, Mr. Mitchell's company simplified the process and used water …."); *see also* Daniel R. Cahoy, Joel Gehman & Zhen Lei, *Fracking Patents: The Emergence of Patents as Information-Containment Tools in Shale Drilling*, 19 MICH. TELECOMM. & TECH. L. REV. 279, 285 (2013) (noting that, in 1997, Mitchell energy found that well performance with slickwater hydraulic fracturing "was somewhat better than [with] the crosslinked jobs, but stimulation costs were reduced by approximately 65%"); G. Waters et al., *supra* note 79, at 1 ("In 1997 Mitchell Energy began to experiment with Slickwater stimulation treatments. These treatments contained roughly twice the fluid volume of the large crosslinked treatments previously pumped, but less than 10% of the proppant volume.").

[94] YERGIN, *supra* note 11, at 330.

[95] J. Daniel Arthur, An Overview of Modern Shale Gas Development in the United States 4-5 (2008), *at* http://www.all-llc.com/publicdownloads/ALLShaleOverviewFINAL.pdf (noting that "rapid increases in natural gas prices" in part drove the recent expansion in use of Mitchell's techniques).

[96] *See* Wang & Krupnick, *supra* note 11, at 25 (noting that the Federal Energy Regulatory Commission, at the request of Mitchell and the Texas Railroad Commission—the state's oil and gas agency—approved the designation of the Barnett Shale play as a "tight gas" formation, thus allowing sales of gas at a higher price, but not as high of a price as other types of unconventional gas could receive.

A. PIPELINES AND "PIPELINE NEUTRALITY"

The availability of pipeline infrastructure centrally affects incentives to produce oil and gas. Fossil resources must be extracted in the locations where they are most abundant—this geographic factor is beyond the control of industry—and pipelines must be constructed from regions of abundant oil and gas to the areas of highest demand. Single operators often lack an incentive to build large interstate pipelines themselves. Large pipeline companies with the capital and motivation to build an interstate pipeline have no desire to share pipeline space with others, as this would merely enable competitors to access the captive markets served by the pipeline builder and operator. Further, historically fragmented state policies for the siting of energy infrastructure threatened to block pipeline construction. Government support addressed these problems, providing federal siting and eminent domain authority to ease the construction process and regulating interstate pipeline prices to avoid monopolist pricing. Eventually, the federal government also required open access to pipelines, thus allowing for more competition in gas production. These changes, along with technological improvements, occurred slowly, but by the late 1990s, they had converged to create abundant pipeline capacity that helped spur new natural gas production for sale to out-of-state markets.

As Alexandra Klass and Danielle Meinhardt describe in their thorough historical analysis of pipeline development, when large natural gas fields in Kansas, Oklahoma, and Texas were discovered in 1918, improved technologies for welding, stronger pipeline materials, and better compressors necessary for transporting natural gas long distances were starting to emerge, leading to the development of "twelve major gas transportation systems" between 1927 and 1931.[97] But these pipelines did not form a national network, resulting in an abundance of gas in the Texas region and a shortage in the Northeast. Inconsistent state regulations of pipelines and the prices they charged also impeded pipeline development.[98] The U.S. Supreme Court declared in 1924 that states could not regulate interstate pipelines. Although this made interstate pipeline construction and operation easier, it opened up a regulatory gap, as there was no federal or state regulation of interstate pipelines.[99] Interstate pipeline companies, which owned pipelines, purchased gas from producers, and sold the gas to instate and out-of-state consumers, became monopsonists and oligopolists

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[97] Alexandra B. Klass & Danielle Meinhardt, *Transporting Oil and Gas: U.S. Infrastructure Challenges* at 41, draft (forthcoming 2014).

[98] *Id*. at 42.

[99] Missouri v. Kansas Gas Co., 265 U.S. 298 (1924); *see also* Klass & Meinhardt, *supra* note 97, at 42 (also discussing the case).

(typically simply called monopolists, although in some cases more than one pipeline was available within a region): a small group of companies with the capital needed to construct expensive pipelines were, for the most part, the sole purchasers and sellers of gas.[100]

In the 1930s, monopoly pricing, combined with the availability abundant gas in the Texas region and scarcity in the Northeast, induced a diverse group of lobbyists to demand federal intervention.[101] This group included a coalition of cities that wanted better access to gas, the coal industry that believed federal regulation would "drive up prices," and producers and consumers who suffered from high interstate pipeline prices.[102] At the recommendation of the Federal Trade Commission, which conducted an extensive study of interstate natural gas and monopolistic practices, Congress passed the Natural Gas Act of 1938, providing for federal authority over the interstate transportation of natural gas, among other interstate gas activities.[103] The Federal Power Commission, and later FERC, regulated natural gas prices,[104] approved certificates for new interstate pipelines,[105] and granted eminent domain authority for the siting of pipelines,[106] allowing an interstate network of natural gas pipelines to flourish.

Although federal regulation of pipelines and technological improvements incentivized the construction of interstate pipelines and controlled pricing, access to pipelines remained limited. Natural gas pipeline companies' rates were capped, but these companies were not required to allow producers to use the pipelines. As a result, a number of producers had only limited access to markets. Beginning in 1976, however the FPC began to open up pipeline access to all producers.[107] A second order (now from FERC) in 1979 further supported sales directly from producers to consumers, with pipelines acting simply as the intermediaries.[108] Later, FERC Order 436 of 1985 allowed pipelines to

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[100] *See* Richard J. Pierce, Jr., *Reconstituting the Natural Gas Industry From Wellhead to Burnertip*, 25 ENERGY L.J. 57, 60-61 (2004).
[101] Klass & Meinhardt, *supra* note 97 [xx not hyperlinked], at 42.
[102] *Id*. at 42-43.
[103] 15 U.S.C. §§ 717-717z (1982).
[104] 15 U.S.C. § 717e; 15 U.S.C. §717c(a).
[105] 15 U.S.C. § 717f(f).
[106] 15 U.S.C. § 717f(h).
[107] *Freeing the Captives: Nondiscriminatory Access to Transportation in the Interstate Natural Gas Market*, 47 U. Pitt. L. Rev. 843, 849 (1985-1986) (describing FPC Order No. 533, issued in 1975, which was "a policy statement by the FPC that it would approve applications for certificates to transport gas sold by producers directly to high priority users").
[108] *Id*. at 850 (describing FPC Order No. 30).

choose to offer open access service, under which they could allow third party producers to use their lines for transport. If these pipelines allowed any third party use, they had to offer it to all producers on a non-discriminatory basis.[109] The Order incentivized pipelines to switch to open access status by providing expedited FERC approval for new facilities these pipelines might need to build. Finally, FERC Order 636 in 1992 dramatically restructured the pipeline business, requiring all interstate pipelines to offer open access service on a non-discriminatory, first come, first-served basis. The pipelines had to functionally unbundle their gas production, transport, and sales functions, and could not favor themselves in transport prices.

When producers, including smaller "independents" like Mitchell Energy, could directly access larger numbers of distant purchasers—particularly those in the Northeast that badly needed natural gas at the time—they could make potentially lucrative returns. The prospect of such returns incentivized gas production, including the development of more expensive, less accessible gas reserves that required sophisticated technologies for extraction. As "commons" theorists would likely acknowledge,[110] it seems unlikely to be mere coincidence that FERC's adoption of a policy of "pipeline neutrality" was followed within about a decade by Mitchell Energy's breakthroughs and subsequent market recognition of the commercial feasibility of shale gas extraction.[111]

B. OIL AND GAS MARKETS

As pipeline policy gradually expanded access to the infrastructure needed by natural gas producers, federal pricing policies also attempted to encourage the production of oil and natural gas from unconventional

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[109] *See* Thomas P. Lyon & Steven C. Hackett, *Bottlenecks and Governance Structures: Open Access and Long-Term Contracting in Natural Gas*, 9 J. L Econ. & Org. 380, 387 (1993).

[110] *Cf.* Yochai Benkler, *Commons and Growth: The Essential Role of Open Commons in Market Economies*, 80 U. CHI. L. REV. 1499, 1504 (2013) (reviewing BRETT M. FRISCHMANN, INFRASTRUCTURE: THE SOCIAL VALUE OF SHARED RESOURCES (2012)) ("Rapid growth and change … depend on significant levels of freedom to operate … and therefore require substantial commons in resources.").

[111] Michael Shellenberger, Interview with Dan Steward, Former Mitchell Energy Vice President (Dec. 12, 2011) (recording Steward's statements that Mitchell Energy had proven shale gas's commercial viability by 2000 and that financial markets ultimately recognized this in 2002), *available at* http://thebreakthrough.org/archive/interview_with_dan_steward_for (last visited Feb. 6, 2014).

formations.[112] A Supreme Court decision in the 1950s had forced the FPC and later FERC to regulate all prices of gas at the wellhead if that gas was eventually to be sent interstate.[113] Such regulation effectively discouraged the overall production of natural gas, including unconventional natural gas, because it limited the interstate gas market. As the interstate price was capped, producers commonly had little incentive to sell gas to distant interstate users who badly needed the gas. Particularly for unconventional gas for which extraction was unusually costly, producers frequently could not expect to recover their costs of production or make substantial profits by selling interstate.

Government attempts to improve the functioning of gas markets followed. In the 1960s, FERC attempted to enhance the production of domestic gas without causing excessive growth of consumer prices, and it did this by setting lower prices for gas from existing wells that was sold interstate and allowing higher prices for interstate gas produced from newly drilled wells.[114] But shortages remained, and an increasingly complex pricing scheme resulted in an overall decline of the "total quantity of gas available to the market."[115] Congress later incentivized the production of "deep" gas and "tight gas"—resources that tended to require unconventional technologies like horizontal drilling (and ultimately fracturing). It did this through the Natural Gas Policy Act of 1978, which allowed producers to charge higher interstate rates for gas produced from unconventional formations—gas that was badly needed in markets in the Northeast, in particular, and could bring high sales prices. In 1989, Congress fully deregulated the price of natural gas at the wellhead—although Congress provided several transition years for price deregulation to take complete effect. Deregulation allowed all producers to charge market prices for all types of gas.[116] Rates for pipeline service, however, remained regulated.

In short, gradual changes in pricing policies, combined with incentives for the construction and operation of pipelines and requirements for open access to these pipelines, created the national market that was necessary to support high-priced drilling and fracturing by a multitude of independent

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[112] Pierce, *supra* note 100; Richard J. Pierce, Jr., *Natural Gas Regulation, Deregulation, and Contracts*, 68 VA. L. REV. 63, 66 (1982).
[113] Phillips Petroleum Co. v. Wisconsin, 347 U.S. 672 (1954); *see also* Pierce, *supra* note 112, at 66 (discussing the Supreme Court decision and FERC's previous interpretation of its authority).
[114] Pierce, *supra* note 112, at 68.
[115] Pierce, *supra* note 112, at 69.
[116] Natural Gas Wellhead Decontrol Act of 1989.

producers.[117] By the 1990s, the foundations for a vibrant national market in natural gas—open-access interstate pipelines and favorable pricing policies—were essentially in place.

III. SUB-INNOVATIONS SUPPORTING ADVANCES AT THE WELLHEAD

With the improvement of infrastructure, infrastructural policies, and national markets needed to support unconventional oil and gas development, more operators were incentivized to seek out less accessible reserves. In so doing, they made use of a great variety of technological advances. The horizontal drilling and hydraulic fracturing techniques behind the modern unconventional natural gas boom are the result of numerous innovations that occurred well beyond the oil and gas industry. They are also the product of decades of experimentation within the industry at offshore and onshore well locations around the globe. This Part discusses a number of innovations that helped bring about a revolution in capacities to access unconventional sources of natural gas. In so doing, the discussion highlights complexities of the innovation process that are typically overlooked in the Mitchell myth.

As introduced in Part I, the modern fracking revolution involves two core techniques—horizontal drilling and slickwater hydraulic fracturing—that are effective in densely-packed, low permeability shale and tight sandstone formations around the United States. These techniques were only fully perfected in the past few years, and they continue to improve. Yet the combination of horizontal drilling and fracturing alone was still not enough to create the level of production many operators hoped for, and this insufficiency led to further innovations. In light of the expense of horizontal drilling and fracturing, operators needed better production numbers, and the key to improved production came from a technology used by operators in the Bakken Shale of North Dakota and Montana—a shale that contains large quantities of oil. These and other operators discovered that fracturing the shale around a lateral wellbore in isolated, discrete stages created better results.[118] By isolating portions of the lateral wellbore using equipment called "packers," the pressure within each portion of the lateral could be better maintained, thus allowing more fractures to be propagated

[117] One could argue that without federal intervention, we would not have had the pricing problems initially created by interstate price caps. This is true, but the specific incentives provided to tight and deep gas on the interstate market—although part of a generally problematic pricing policy—did serve to encourage the development of unconventional resources.
[118] Wiseman, *Untested Waters*, *supra* note 26.

around the well.[119] Further, the use of multilateral horizontal wells, in which operators drill one vertical wellbore and numerous lateral bores from this well, has substantially reduced costs and allowed for even more access to gas,[120] and 3D seismic imaging and microseismic mapping allowed operators to better identify gas resources and measure and model effective fracturing techniques.[121]

Patents had an early role in shale gas development, although in a quite indirect fashion. It appears that one early source for notions of drilling horizontally through rock came from an 1891 patent for a flexible drilling shaft, which the inventor envisioned would be used by dentists but also "for flexible shafts of cables of larger size—such as, for example, … for drilling holes in boiler-plates and other like heavy work."[122] The first successful commercial horizontal drilling tests in the oil and gas sector occurred several decades later; they were initiated by a French operator that worked in southwestern France and offshore Italy "between 1980 and 1983."[123] These techniques were soon applied commercially in the United States, with horizontal wells being drilled in North Dakota's Bakken Shale and Texas's Austin Chalk formation during "the late 1980's."[124] More recent advances in horizontal drilling enabled the drilling of longer bores: underground measurement while drilling (MWD) or logging while drilling (LWD)

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[119] Clarke et al., *supra* note 66, at 3 ("Approximately 1,000 feet of wellbore if hydraulically fractured at a time, so each well must be hydraulically fractured in multiple stages, beginning at the furthest end of the wellbore.").

[120] Steve Bosworth et al., Key Issues in Multilateral Technology, http://www.slb.com/~/media/Files/resources/oilfield_review/ors98/win98/key.pdf.

[121] Wang & Krupnick, *supra* note 11, at 10, 14; NAT'L RESEARCH COUNCIL, *supra* note 37 (describing horizontal drilling, hydraulic fracturing, and 3D seismic mapping as the three technologies that spurred the boom).

[122] Energy Info. Admin., *supra* note 78, at 7; U.S. Patent Office, John Smalley Campbell, Flexible Driving-Shaft, Specification forming part of Letters Patent No. 459,152, Sept. 8, 1891.

[123] Lynn Helms, Horizontal Drilling, https://www.dmr.nd.gov/ndgs/newsletter/NL0308/pdfs/Horizontal.pdf. The Energy Information Administration notes that earlier limited horizontal drilling also occurred, with "[t]he first recorded true horizontal oil well, drilled near Texon, Texas" completed in 1929, another in 1944 in Pennsylvania, and still others in China in 1957 and "later" in the Soviet Union, but observes that "little practical application occurred until the early 1980s." Energy Info. Admin., *supra* note 78, at 7. Note that the U.S. government was not, for the most part, involved in horizontal drilling research or direct financial support. NAT'L RESEARCH COUNCIL, *supra* note 37, at 13 (describing the government role in this area as "absent or minimal"); Wang & Krupnick, *supra* note 11, at 10 (also noting the lack of government involvement in horizontal drilling).

[124] Energy Info. Admin., *supra* note 78, at vii.

provided a better understanding of the formation to be targeted,[125] and, as introduced in Part I, downhole motors with three-dimensional control enabled more accurate orientation of the drill bit.[126]

When hydraulic fracturing was combined with horizontal drilling techniques, even better results emerged. Oil and gas companies have experimented with hydraulic fracturing and its predecessors for more than half a century. Predecessor techniques to fracking were quite blunt, but were commonly used and had the same purpose: to create fractures in a formation to release oil and gas. Beginning in the 1860s, operators dropped nitroglycerin down a well, and the underground explosion opened up rocks surrounding the well, often aiding oil and gas flow.[127] By the 1930s, enterprising individuals injected acid down wells to open up fractures in formations around the wells.[128] Neither of these techniques, however, used hydraulic forces to fracture formations. Hydraulic fracturing emerged in 1947, when Floyd Harris of Stanolind Oil and Gas Corporation (later Amoco) performed an experimental "hydrafrac" in Kansas, using 1,000 gallons of gasoline thickened with napalm followed by a gel injection to fracture a 2,400-feet limestone formation.[129] Operators experimented with various combinations and concentrations of gels, sand, and water (and sometimes foam)—often varying the technique for different formations.[130] In the late 1990s, Mitchell Energy perfected the slickwater technique, which borrowed from and modified earlier fracturing techniques.

Even after the introduction of highly successful slickwater fracturing in the late 1990s, further innovations have occurred. Fracturing service companies have experimented with new friction reducers that do not damage the shale or tight sandstone formation being fractured, for example, thus enabling better production from the formation, and they have published their results in petroleum engineering journals.[131]

As Zhongmin Wang and Alan Krupnick explain in a detailed analysis of fracturing innovation, technological advances beyond the wellhead were also crucial components of innovation. In the 1980s industrial actors improved 3D seismic imaging techniques that allowed for better identification of available gas resources underground, and such techniques

[125] *See, e.g.*, Weatherford Magazine, Technology Incubators at 12.
[126] *See supra* notes 81-83 and accompanying text.
[127] Montgomery & Smith, *supra* note 17, at 26-27.
[128] *Id*.
[129] *Id*.
[130] *See supra* note 12 and accompanying text.
[131] *See* Hong Sun et al., *A Nondamaging Friction Reducer for Slickwater Frac Applications*, SOC'Y PETROLEUM ENG'RS 139480 (2011).

further improved with advances in computing technology.[132] A DOE seismic imaging program that began in 1988 provided additional support.[133] The government played a much larger role in microseismic fracturing mapping, wherein industry drills a monitoring well near a hydraulic fracturing job and measures various attributes of the fractures, thus allowing assessment of the fracturing and improvement of future fracturing techniques. DOE-sponsored mapping research at Los Alamos National Laboratory, originally designed to relate to geothermal energy development, and a "DOE Multiwell Site experiment in Colorado" further advanced these technologies.[134]

Horizontal drilling, slickwater fracturing, packers that allowed for isolated fracturing treatments, and improved assessments of gas location and fracturing effectiveness all converged, along with market and infrastructural changes, to support the modern gas boom. These advances provide a picture of innovation that extends far beyond the Mitchell story, revealing the complex technologies that grew from experimentation within the industry, other technological advances such as improved computers, and government support.

IV. GOVERNMENT SUPPORT AT THE WELLHEAD

External market and infrastructural support and cross-sector innovations and sub-innovations were not the only necessary pieces of fracking innovation. The oil and gas industry also benefited from direct governmental support for horizontal drilling and hydraulic fracturing through research projects, public-private partnerships, tax preferences, loans and loan guarantees, [135] and regulatory exemptions that developed over time as the industry changed.

A. PUBLICLY FUNDED RESEARCH AND PUBLIC-PRIVATE PARTNERSHIPS

The U.S. government funded or performed both basic and applied research that helped prime the pump for the ultimate shale gas boom. Energy crises of the early and mid-1970s prompted Congress and President

[132] Wang & Krupnick, *supra* note 11, at 13.
[133] *Id*. at 13-14.
[134] *Id*. at 14.
[135] *See* Congressional Budget Office, Federal Financial Support for the Development and Production of Fuels and Energy Policies 1 (2012), http://www.cbo.gov/sites/default/files/cbofiles/attachments/03-06-FuelsandEnergy_Brief.pdf (describing support through financial mechanisms, including direct funding and tax preferences, and research .

Ford to create the Energy Research and Development Administration (ERDA) in 1976, with promotion of "Unconventional Gas Research" as one of its goals.[136] ERDA promptly began collaborating with universities and industry to "develo[p] an inventory of the unconventional gas resources across several regions,"[137] and ERDA's 1977 successor, the U.S. Department of Energy (DOE), continued its work in this area.[138]

For our purposes, perhaps the most important program initiated by ERDA was the Eastern Gas Shales Program (EGSP), which ERDA launched in 1976 and the DOE sustained until 1992.[139] In 1975, the federal government had partnered with industry to drill the "first Appalachian Basin directional wells to tap shale gas, and shortly thereafter completed the first horizontal shale well to employ seven individual hydraulically fractured intervals."[140] Building from these successes, EGSP focused on the Devonian shales of the Appalachian, Michigan, and Illinois Basins.[141] Through EGSP, ERDA worked with industry, universities, and state geological surveys[142] "to assess the resource base, in terms of volume, distribution, and character" and also to develop technologies, including massive hydraulic fracturing, for monitoring and completing drilling of wells to exploit those resources.[143] The EGSP supported the drilling of about 35 experimental wells that demonstrated, among other things,

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[136] *Executive Summary*, *in* BURWEN & FLEGAL, *supra* note 53, at 2 ("In 1976, Congress funded the Energy Research and Development Administration … to launch the Unconventional Gas Research (UGR) program.").
[137] *Id.*
[138] NAT'L RESEARCH COUNCIL, *supra* note 37, at 1.
[139] *Id.* at 201.
[140] U.S. DEPT. OF ENERGY, NATL. ENERGY TECH. LAB., SHALE GAS: APPLYING TECHNOLOGY TO SOLVE AMERICA'S CHALLENGES 5 (2011) [hereinafter "NETL REPORT"], *available at* http://www.netl.doe.gov/technologies/oil-gas/publications/brochures/Shale_Gas_March_2011.pdf.
[141] *See* U.S. DEPARTMENT OF ENERGY, DOE'S UNCONVENTIONAL GAS RESEARCH PROGRAMS 1976-1995: AN ARCHIVE OF IMPORTANT RESULTS 16 (2007) (discussing the Appalachian, Illinois, and Michigan Basins in relation to "[t]hick Devonian-age black shales underl[ying] extensive areas of the eastern United States").
[142] Leo A. Schrider & Robert L. Wise, *Potential New Sources of Natural Gas*, J. PETROLEUM TECH., Apr. 1980, at 703, 704.
[143] NAT'L RESEARCH COUNCIL, *supra* note 37, at 201; *cf.* Schrider & Wise, *supra* note 142, at 709 (reporting that, by 1980, "36 stimulation treatments [of wells, at least some involving a form of hydraulic fracturing,] ha[d] been performed in 22 Devonian shale wells"); *see also* Energy Systems Planning Div., Coring and Logging Plan, Eastern Gas Shales Project, http://www.netl.doe.gov/kmd/cds/disk7/disk1/EGS%5CCoring%20and%20Logging%20Plan,%20Eastern%20Gas%20Shales%20Project.pdf (1977).

possibilities for horizontal drilling.[144] The EGSP also supported "theoretical and experimental research on hydraulic fracturing by Lawrence Livermore Laboratory" and collaborative work on fracturing by the Stanford Research Institute, Sandia Laboratories, and others.[145] In total, the EGSP spent about $185 million in 2011 dollars,[146] with peak spending occurring during the first several years of the program.[147]

The amounts spent by the EGSP were modest in the context of overall spending of tens of billions of dollars by industry and government on energy-related research and development.[148] But the EGSP's contributions came at critical times when the possibilities for exploitation of shale gas reserves were poorly understood,[149] when large oil and gas companies were reducing investment in research and development,[150] and when, as has continued to be the case, the field of unconventional gas recovery was largely dominated by relatively small independents with limited budgets for research and development.[151] As one set of commentators concluded, "[t]he

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[144] BURWEN & FLEGAL, *supra* note 53, at 3 ("The EGSP resulted in the drilling and coring of approximately 35 experimental wells in Devonian shales of the Appalachian basin, which revealed the impact of horizontal drilling on shale gas recovery."). *See also* Thaddeus S. Dyman, U.S. Dept. of Interior Geological Survey, Eastern Gas Shales Project (EGSP) Data Files: A Final Report (1981), http://www.netl.doe.gov/kmd/cds/disk7/disk1/EGS%5CEastern%20Gas%20Shales%20Project%20%28EGSP%29%20Data%20Files%20A%20Final%20Report.pdf.

[145] Schrider & Wise, *supra* note 142, at 709.

[146] BURWEN & FLEGAL, *supra* note 53, at 3.

[147] NAT'L RESEARCH COUNCIL, *supra* note 37, at 201 ("DOE expenditures from 1978 through termination of the program in 1992 amounted to $137 million (1999 dollars), with about two-thirds of the total having been expended between 1978 and 1982."); BURWEN & FLEGAL, *supra* note 53, at 3 (reporting that the EGSP's peak budget was $18 million (or $47 million in 2011 dollars) in 1979).

[148] *Cf.* NAT'L RESEARCH COUNCIL, *supra* note 37, at 1 ("From 1978 through 1999, the federal government expended $91.5 billion (2000 dollars) on energy R&D, mostly through DOE programs. This direct federal investment constituted about a third of the nation's total energy R&D expenditure."); THE FUTURE OF NATURAL GAS: AN INTERDISCIPLINARY MIT STUDY 160 (2011) [hereinafter "MIT STUDY"] ("Relative to the role of natural gas in the energy sector, the Department of Energy (DOE), the lead government funder of energy RD&D has historically had very small programs dedicated to natural gas exploration, production, transportation and use.").

[149] *See* NAT'L RESEARCH COUNCIL, *supra* note 37, at 201 ("The DOE program was responsible for bringing together and integrating a significant amount of scattered data on the Eastern gas shales critical to a solid assessment of the resource base.").

[150] BURWEN & FLEGAL, *supra* note 53, at 5 ("Starting in the early 1980s, major oil and gas companies began to decrease their research and development spending ….").

[151] *See* NAT'L RESEARCH COUNCIL, *supra* note 37, at 201 (describing the EGSP as "designed to assess the resource base … and to introduce more sophisticated logging and completion technology to an industry made up mostly of small, independent producers");

resulting maps and technical reports both proved the extent of shale gas resources and shared technological know-how with industry, demonstrating market potential and lowering risks to early entrants."[152] Resource estimates of the kind generated by the EGSP are essential for the industry, as they help determine where productive wells might most reasonably be drilled and fractured. Mitchell and his staff themselves studied EGSP data in support of their efforts to "crack" the Barnett Shale even though that formation was not part of the Devonian formations on which the EGSP focused.[153]

A number of the EGSP's investments turned out to be not only relatively well targeted, but also well leveraged through the DOE's partnerships with other actors and especially the Gas Research Institute (GRI), "a private non-profit research management organization formed in 1976 and funded through a FERC-sanctioned surcharge placed on interstate pipeline gas volumes."[154] From the start, a goal of the EGSP was to "encourag[e] private industry to initiate and direct R&D projects by sharing the risks and costs of development."[155] In turn, GRI, with which the DOE extensively coordinated, was perhaps the leading embodiment of the public-private partnership model that informed much energy-related research in the area.

GRI, which had "members from all three segments of the industry—producers, pipelines, and local distribution companies"—acted "as the R&D arm of the natural gas industry," a regulated industry that policymakers had believed to have failed to invest sufficiently in research and development.[156] GRI had much more money at its disposal than did the EGSP: its "early budget was approximately $40 million per year, growing to $200 million per year in the 1990s."[157] GRI's peak annual budgets thus exceeded the total amount spent by the EGSP during the decade and a half of its

Executive Summary, *in* BURWEN & FLEGAL, *supra* note 53, at 2 ("[T]he Eastern Gas Shales Project (EGSP) determined the recoverable reserves of Devonian shale gas and financed experimental shale wells—at a time when most firms in unconventional gas recovery had little or no research budgets.").

[152] *Executive Summary*, *in* BURWEN & FLEGAL, *supra* note 53, at 2.

[153] Loren Steffy, *How Much Did the Feds Really Help with Fracking?* (Oct. 31, 2013), at http://www.forbes.com/sites/lorensteffy/2013/10/31/how-much-did-the-feds-really-help-with-fracking/ .

[154] MIT STUDY, *supra* note 148, at app.8A:3.

[155] Schrider & Wise, *supra* note 142, at 704.

[156] William M. Burnett, Dominic J. Monetta & Barry G. Silverman, *How the Gas Research Institute (GRI) Helped Transform the US Natural Gas Industry*, 23 INTERFACES 44, 45 (1993) ("Regulated industries, most notably electric and gas utilities, historically have underinvested in R&D.").

[157] BURWEN & FLEGAL, *supra* note 53, at 4.

existence.[158] Of likely significance for businesses looking for assurance in making long-range plans, GRI's funding was relatively stable and "independent of annual Congressional appropriations."[159]

Consistent with the nature of GRI's membership, GRI "was dedicated to natural gas [research, development, and demonstration] across the value chain," from wellhead to consumer.[160] Overall, GRI's work had a more applied focus than the DOE's work,[161] with GRI concentrating on "commercialization and deployment of technologies that were of interest to the industry, including new logging techniques, reservoir models, and simulation technologies."[162] But the work of the DOE and GRI was not purely complementary: they sometimes collaborated directly, as in combining with private companies to fund the drilling of experimental horizontal wells.[163] Indeed, the reduction in DOE funding for natural gas research and development in the 1980s has been at least partly attributed to the availability of funding through GRI.[164]

DOE and GRI funding and leadership helped set the technological agenda for improving and building new approaches to natural gas development, as well as encouraging information sharing and diffusion of new techniques. As a condition of the federal support for GRI, GRI projects were required to publish all findings, and industry partners were required to surrender claims to intellectual property rights in these findings.[165] "Moreover, FERC made GRI indifferent to [intellectual property] royalties by subtracting any royalties from FERC funding; this

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[158] *See supra* text accompanying notes __.
[159] *Id.*
[160] MIT STUDY, *supra* note 148, at 160.
[161] BURWEN & FLEGAL, *supra* note 53, at 4 ("DOE concentrated on basic research R&D to generate more data on and develop new exploration and production techniques, while the GRI program focused on commercialization and deployment of technologies for industry.").
[162] MIT STUDY, *supra* note 148, at app.8A:5.
[163] *Executive Summary*, *in* BURWEN & FLEGAL, *supra* note 53, at 2 ("Experimental wells for shale gas, drilled conjointly with DOE, GRI, and individual companies, proved methods for the industry at a time when no firm was willing to try on its own."); *see also* MIT STUDY, *supra* note 148, at app.8A:4 (noting that GRI "sometimes provid[ed] substantial industry match into the smaller DOE programs").
[164] MIT STUDY, *supra* note 148, at app.8A:4 ("To a large extent, the sharp decrease in the DOE natural gas [research, development, and demonstration] program funding in the 1980s is attributable to the existence of the larger GRI program and the prevailing view that oil and gas RD&D could be left to industry.").
[165] BURWEN & FLEGAL, *supra* note 53, at 5.

ensured that GRI focused on technology diffusion as much as possible, rather than [on] support[ing] itself from licensing income."[166]

Quite generally, GRI appears to have helped foster an environment favorable to adoption of new technologies by independent producers, and GRI collaborated with such producers extensively. The GRI board apparently showed a solid capacity to respond to input from industry[167] and to promote information exchange with the DOE itself. Mitchell Energy was on the GRI board, and Mitchell's persistence was "generally credited with establishing the GRI focus" on unconventional natural gas.[168] In turn, the GRI board "convinced DOE to refocus away from Eastern Gas shales to first Michigan's Antrim shales and then Texas' Barnett shales," where the revolution ultimately took off.[169]

Deregulation of the natural gas industry ultimately led to the termination of GRI, which was replaced by the Gas Technology Institute in 2000 and then, after the ending of the FERC surcharge in 2004, the Royalty Trust Fund, which has a narrower focus on production and a research budget less than one fourth that of GRI at its peak.[170] But by the late 1990s, when Mitchell made his great breakthrough with slickwater hydraulic fracturing, GRI had already done much to pave the way for the shale gas boom of the next decade. Indeed, in 1991, Mitchell had begun working directly with the DOE and GRI, joining with them over a period of several years to fund the drilling of Mitchell's first horizontal well and, more generally, to develop the knowledge and techniques that ultimately "cracked" the Barnett Shale.[171]

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[166] *Id.*

[167] Burnett, Monetta & Silverman, *supra* note 156, at 46 ("GRI uses a comprehensive strategic planning and analysis approach with wide-ranging advisory input to develop its annual five-year plan ….").

[168] MIT STUDY, *supra* note 148, at app.8A:5.

[169] BURWEN & FLEGAL, *supra* note 53, at 5.

[170] MIT STUDY, *supra* note 148, at app.8A:5-6.

[171] Michael Shellenberger, Interview with Dan Steward, Former Mitchell Energy Vice President (Dec. 12, 2011) (quoting a former Mitchell Energy vice president as saying that, through the end of the 1990s, the federal government and GRI helped Mitchell Energy develop knowledge about the Barnett Shale, drill its "first horizontal well," map cracks, and work on "re-fracks of shale wells"), Breakthrough Institute, http://thebreakthrough.org/archive/interview_with_dan_steward_for (visited Feb. 6, 2014). *See generally* Alex Trembath, History of the Shale Gas Revolution (Dec. 14, 2011) ("In 1991, Mitchell partnered with DOE and the federally funded Gas Research Institute (GRI) to develop tools that would effectively fragment formations in the Barnett Shale, the massive Texan field that now produces over 6% of all domestic natural gas."), http:/thebreakthrough.org/archive/history_of_the_shale_gas_revolution (visited on Feb. 4, 2014).

In addition to helping individual operators like Mitchell, DOE and GRI helped foster a number of specific technologies. DOE and GRI contributions to demonstrations and development of techniques of horizontal drilling and hydraulic fracturing have already been noted.[172] Other key technologies to which DOE and GRI contributed were polycrystalline diamond drill bits,[173] measurement and logging of critical data while drilling,[174] and 3D seismic imaging.[175]

The story of DOE's support of innovation in drill bits is of particular interest because of what it tells about the unpredictable path that breakthrough innovations can take. In the 1970s, the DOE supported the development of new drill bits "that would be more suitable than traditional drill bits for the high-density, high-temperature applications needed to drill geothermal wells."[176] Fortuitously, the resulting polycrystalline diamond bits turned out to be tremendously useful in drilling oil and gas wells and lowered drilling costs substantially[177]—a development that was presumably particularly important for the drilling of long horizontal wells through concrete-like shale rock. A recent study estimates that the new polycrystalline drill bits yielded cost savings of $15.6 billion from 1982 to 2008, with half of this added value attributed to the DOE's investment of a mere $26.5 million during that period.[178]

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[172] *See supra* text accompanying notes __.

[173] *See infra* text accompanying notes __.

[174] NAT'L RESEARCH COUNCIL, *supra* note 37, at 195 (noting that the DOE "supported a field demonstration of [mud pulse telemetry] in its very early and critical phase of development"). The Department of Energy also suggests that modern directional drilling technologies such as electromagnetic telemetry had their "roots in DOE research from the 1980s and 90s." NETL REPORT, *supra* note __, at 6.

[175] NAT'L RESEARCH COUNCIL, *supra* note 37, at 208, 211 (noting that, although "[t]he advances in seismic technology have been developed mostly by industry," "federal government funding geared to certain niche areas—for instance, cross-well seismic, utilization of special expertise and facilities such as the high-performance computing capabilities of the national laboratories, or the support of seismic surveying for independent operators …—is a useful adjunct to a major private sector activity").

[176] GALLAHER, LINK & O'CONNOR, *supra* note 86, at 97.

[177] *Id.* at 97 ("Approximately 60 per cent of worldwide oil and gas well footage in 2006 was drilled using PDC drill bits …. [They] yiel[ded] a present value cost savings of $15.6 billion from 1982 to 2008.").

[178] *Id.* at 97; *see also id.* at 98 (crediting DOE with "significant contributions to (1) developing the bit and getting it to the market, (2) overcoming performance flaws, and limitations, and (3) spurring the innovation that resulted in overall market success.").

B. TAX RELIEF

Government support for new and improved oil and gas development techniques has included a variety of tax incentives and regulatory exemptions. The tax benefit that tends to draw the greatest attention in this context is the section 29 tax credit for "natural gas production from unconventional natural gas wells drilled between 1980 and 1992," which "extend[ed] to natural gas produced from those wells until 2002."[179] This tax credit, which Congress enacted as part of the Windfall Profits Tax Act of 1980,[180] generated tax savings of about $10 billion for operators between 1980 and 2002,[181] including about $760 million in savings in 1993 alone.[182] Although these savings were shared with developers of other unconventional gas sources such as coalbed methane, the numbers suggest that the tax credit made financial contributions to shale gas development at least on the order of the direct monetary contributions to shale gas development made by GRI and DOE combined.[183] Even small operators who lacked substantial tax liabilities were able to benefit from the credits by engaging in tax equity financing transactions win which they "effectively 'sold' their credits to larger firms."[184] Once again, Mitchell Energy took advantage of the opportunity for government assistance, using tax credits to "hel[p] underwrite the cost of developing hydraulic fracturing."[185]

Beyond the now-defunct section 29 credit, there are a wide variety of still-extant "lenient rules regarding the recognition, timing, character, and calculation of taxable profits [that] create large [effective] subsidies for taxpayers engaged in" oil and gas production.[186] For independent producers, aggregation of these various additional incentives can result in a double-digit "negative tax rate" that substantially increases pretax returns on investment.[187] Many of these tax preferences are controversial:[188] the

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[179] MIT STUDY, *supra* note 148, at app.8A:5; *see also* YERGIN, *supra* note 11, at 328 ("Fortunately, something of a carrot was available, what was called Section 29 …. Over the years, that incentive did what it was supposed to do—it stimulated activity that would otherwise not have taken place.").
[180] *Executive Summary*, *in* BURWEN & FLEGAL, *supra* note 53, at 2.
[181] Kevin Begos, *Fracking Developed with Decades of Government Investment*, Huffington Post, Sept. 23, 2012, *available at* http://www.huffingtonpost.com/2012/09/23/fracking-developed-government_n_1907178.html (visited on Feb. 4, 2014).
[182] MIT STUDY, *supra* note 148, at app.8A:5.
[183] *See supra* text accompanying notes __.
[184] BURWEN & FLEGAL, *supra* note 53, at 7.
[185] Steffy, *supra* note 153.
[186] John A. Bogdanski, *Reflections on the Environmental Impacts of Federal Tax Subsidies for Oil, Gas, and Timber Production*, 15 LEWIS & CLARK L. REV. 323, 324 (2011).
[187] *See* Calvin H. Johnson, *Accurate and Honest Tax Accounting for Oil and Gas*, 125 TAX NOTES 573, 573, 577 (2009) (calculating "a negative tax rate or a subsidy 42 percent"

Obama Administration has repeatedly proposed repealing a number of them.[189] But for purposes of this study, the key point is that, to the extent these more general tax preferences succeeded in attracting investment either in shale gas extraction or in associated technologies,[190] they too contributed to the shale gas boom.

One of these tax preferences, the "percentage depletion allowance,"[191] is of particular interest because, since 1975, it has been available only for independent producers—i.e., non-vertically integrated "producers that do not have refining and retailing operations, and are unrelated to those that do."[192] Under the percentage depletion allowance, independent producers of oil and gas may "deduct against their gross receipts a depletion amount

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under a model in which "four important tax preferences"—"the expensing of intangible drilling costs, the pool of capital doctrine, the percentage depletion allowance, and the domestic manufacturing deduction"—are applied to an investment); Gilbert E. Metcalf, *Taxing Energy in the United States: Which Fuels Does the Tax Code Favor?*, Manhattan Inst. Energy Pol'y & Env't Rep. No. 4, at tab.2 (2009) (estimating effective tax rates of negative 13.5 percent for independent production companies and 15.2% for "integrated firms").

[188] *See, e.g.*, Maura Allaire & Stephen Brown, *Eliminating Subsidies for Fossil Fuel Production: Implications for U.S. Oil and Natural Gas Markets,* Resources for the Future Issue Brief 09-10, at 14 (2009) (noting that "there is divergent opinion about the effects of such subsidies"); Johnson, *supra* note 187, at 573 ("The government should get out of the business of subsidizing oil and gas via the tax system.");

[189] *See* U.S. DEP'T OF THE TREASURY, GENERAL EXPLANATIONS OF THE ADMINISTRATION'S FISCAL YEAR 2010 REVENUE PROPOSALS 59-69 (2009) (explaining proposals to eliminate various tax preferences favoring oil and gas companies); ROBERT PIROG, CONGRESSIONAL RESEARCH SERVICE, OIL AND NATURAL GAS INDUSTRY TAX ISSUES IN THE FY2014 BUDGET PROPOSAL at 2 (2013) (reporting that in 2014 the Obama Administration proposed to eliminate various fossil fuel benefits).

[190] *Cf.* Mona Hymel, *The United States' Experience with Energy-Based Tax Incentives: The Evidence Supporting Tax Incentives for Renewable Energy*, 38 LOY. U. CHI. L.J. 43, 44 (2006) ("Early empirical studies of the impact of oil and gas tax incentives on resource allocation consistently concluded that these special provisions allowed the petroleum industry to maintain a higher level of private investment than it would have absent these policies.").

[191] Johnson, *supra* note 187, at 581.

[192] Bogdanski, *supra* note 186, at 325. *Compare* Stephen L. McDonald, *Distinctive Tax Treatment of Income from Oil and Gas Production*, 10 NAT. RESOURCES J. 97, 98 (1970) (noting that 1926 legislation introduced percentage depletion at a 27.5% rate as a substitute for "discovery-value depletion"), *with* Bogdanski, *supra* note 186, at 325 (describing current provisions for percentage depletion). *See generally* Walter J. Mead, *The Performance of Government in Energy Regulations*, 69 AM. ECON. REV. 352, 352 (1979) (reporting that 1975 legislation "removed the benefits of percentage depletion allowances for integrated oil companies only" but also decreased the allowances for independent producers).

equal to 15% of their oil and gas revenue"—thereby effectively rendering that share of revenue free from tax.[193]

Percentage depletion is a significant benefit that can play a substantial role in generating an effective "negative tax" on production.[194] The Congressional Budget Office (CBO) has estimated that percentage depletion provided $900 million in tax relief in 2011.[195] Even aside from direct benefits to fracking's development through the attraction of additional investment, one might conjecture that the post-1975, independent-producer-favoring rules on percentage depletion helped support the vibrant community of independent producers that spearheaded the shale gas boom while vertically integrated major producers focused elsewhere.[196] Regardless of questions about whether any benefits from percentage depletion are worth its costs, this potential ecosystem-shaping role is notable in light of independent producers' critical part in the fracking revolution.

Another major tax advantage likewise discriminates between independent producers and majors, although only partially. In 1916, the federal government allowed the immediate "expensing of intangible drilling costs (IDCs) and dry hole [non-producing well] costs."[197] This allowance continues and permits operators to fully deduct non-salvageable expenses in the year in which they were incurred, rather than capitalizing them and deducting their value only more gradually through depletion or depreciation.[198] Costs encompassed within this allowance "typically include [those of] labor, fuel, hauling, power, materials, supplies, tool rentals, drilling equipment repairs, and other items incident to and necessary for drilling and equipping productive wells."[199] Congress has specifically

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[193] Bogdanski, *supra* note 186, at 325.

[194] Johnson, *supra* note 187, at 581; *see also* Metcalf, *supra* note 187, at tab.2 (estimating effective tax rates of negative 13.5 percent for independent production companies and 15.2% for "integrated firms").

[195] Congressional Budget Office, Federal Financial Support for the Development and Production of Fuels and Energy Policies 3 (2012), http://www.cbo.gov/sites/default/files/cbofiles/attachments/03-06-FuelsandEnergy_Brief.pdf.

[196] *See supra* text accompanying notes __.

[197] Mary F. Sherlock, Congressional Research Service, Energy Tax Policy: Historical Perspectives on the Current Status of Energy Tax Expenditures 3 (2011); *see also* Bogdanski, *supra* note 186, at 325 ("The intangible costs of drilling and developing domestic oil and gas wells may be deducted immediately, rather than capitalized and recovered over time, at the election of the taxpayer.").

[198] *Id.*

[199] Hymel, *supra* note 190, at 49.

indicated that such costs include expenses from fracturing.[200] Although Congress has not restricted IDC deductions to independent producers, it has applied special limitations to their use by integrated producers: as noted by John Bogdanski in 2011, "[i]ntegrated companies are eligible for the expense election, but the election is limited to 70% of IDC each year; the other 30% must be recovered no more rapidly than through a 60-month amortization."[201]

Like percentage depletion, IDC deduction is viewed as a substantial tax preference. The CBO has estimated that in 2011 this allowance provided a total of $800 million in tax relief.[202] Although such relief was not exclusive to fracking, horizontal drilling, independent producers, or unconventional natural gas, the heavy reliance of hydraulic fracturing and horizontal drilling on special equipment and knowhow suggests that the IDC deductions are likely to have been particularly important for operators of the sorts of unconventional wells that have proliferated in the fracking revolution's wake. Consistent with this sense, the Western Energy Alliance, a trade association formerly known as the Independent Petroleum Association of Mountain States,[203] gave the IDC deductions top billing in a position paper responding negatively to Obama Administration proposals for repeal of various oil and gas tax preferences, including the percentage depletion allowance.[204] The Alliance specifically characterized the IDC deductions as "the R&D program for the oil and natural gas industry," one that "made economically feasible" "[s]hale, tight sands, and other unconventional plays from North Dakota to Colorado to Texas."[205]

Other federal tax rules and provisions have also favored oil and gas production. These include, *inter alia*, depreciation of natural gas pipelines over fifteen years and natural gas gathering lines over seven years; an

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[200] STAFF OF JT. COMM. ON TAX., 99TH CONG., GENERAL EXPLANATION OF THE TAX REFORM ACT OF 1986, at 195 (Jt. Comm. Print 1987) ("IDCs may be paid or accrued to drill, shoot, fracture, and clean the wells.").

[201] Bogdanski, *supra* note 186, at 326. [Check that still currently true.]

[202] Congressional Budget Office, Federal Financial Support for the Development and Production of Fuels and Energy Policies 3 (2012), http://www.cbo.gov/sites/default/files/cbofiles/attachments/03-06-FuelsandEnergy_Brief.pdf.

[203] Western Energy Alliance, About Western Energy Alliance, http://www.westernenergyalliance.org/alliance (last visited Mar. 14, 2014).

[204] Western Energy Alliance, Position Paper, Intangible Drilling Costs (IDC) and Other Deductions Drive Innovation and Job Creation, Mar. 2013 (headlining the proposal for repeal of IDC deductions and discussing this proposal before those for repeal of other tax preferences, such as the percentage depletion allowance), *available at* http://waysandmeans.house.gov/uploadedfiles/western_energy_alliance_wg_comment.pdf.

[205] *Id.*

allowance for "tax-exempt bond-financed prepayments" for natural gas;[206] a deduction for the use of tertiary injectants, such as carbon dioxide, in old reservoirs to wring remaining resources out of them;[207] a "passive loss exception for working interests in oil and natural gas properties";[208] and limited time periods for amortization of "geological and geophysical" expenses (seven years for large, integrated companies and two years for independents[209]) that allow for a higher annual deduction than might otherwise apply.[210] In 2004, Congress added to the list by enacting a general "domestic manufacturing tax deduction" that has enabled oil and gas producers to deduct three to six percent[211] "of the lesser of taxable income or income from domestic 'production' activities" up to a payroll limitation generally set at "50% of the wages that are paid by the taxpayer and allocable to the [relevant] income."[212] Much longer lived has been the "pool of capital doctrine," which for decades has exempted from federal income taxation transfers in which oil and gas producers "compensate landowners, suppliers, and drillers with economic interests in the future profits of their operations."[213]

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[206] Sherlock, *supra* note 197, at 8. An additional benefit that does not contribute to the development of new wells is the marginal well tax credit, implemented in 1994 "to keep low-production oil and natural gas wells in production during periods of low prices for those fuels." PIROG, *supra* note 189, at 3.
[207] PIROG, *supra* note 189, at 4.
[208] *Id*.
[209] Bogdanski, *supra* note 186, at 328.
[210] PIROG, *supra* note 189, at 6-7. Last-in, first-out rules for inventory accounting can also favor oil and gas producers reporting sales of inventory by allowing them to identify "the most recent, usually higher costs with the units that are sold and deductible," while "identify[ing] the lowest costs with the units that have been retained and remain as nondeductible basis." Johnson, *supra* note 187, at 582. "International accounting standards no longer permit use of the LIFO system, but taxpayers who are not subject to those rules (including many U.S. oil companies) can, if they use LIFO on their financial books as well as on their tax returns, reduce their taxable income considerably." Bogdanski, *supra* note 186, at 328.
[211] PIROG, *supra* note 189, at 6 (noting that the deduction began "at 3% in 2005, … rising to a maximum of 9% in 2010," but with a cap of 6% on the rate for oil and gas production).
[212] Bogdanski, *supra* note 186, at 328
[213] Bogdanski, *supra* note 186, at 328. This doctrine treats the transactions in question—including transactions for services that are entirely complete—as non-taxable on the ground that their effect is to generate a sort of joint venture in which the various partners will share in profits that only appear later. Mark P. Gergen, *Pooling or Exchange: The Taxation of Joint Ventures Between Labor and Capital*, 44 TAX L. REV. 519, 520-21 (1989) ("The theory underlying the [pool of capital] doctrine is that people who join in a venture contributing their capital and services for a share of a venture's profits give up and receive nothing. Instead, they pool their resources and keep a corresponding share of profits."); *see also* Johnson, *supra* note 187, at 579 (noting IRS embrace of the doctrine in

Drilling and fracturing operations have further benefited from and continue to enjoy certain state tax advantages. Most states place a severance tax on oil and gas when it is extracted, often in the range of five to seven percent of the market value of the oil and gas sold. Many of these states, however, exempt unconventional or "high-cost" gas from the tax.[214] In Texas in 2006, when the Barnett Shale boom was still in full swing, the state provided more than $1.1 billion to oil and gas companies under its high-cost gas exemption.[215] Pennsylvania's legislature, in turn, repeatedly refused to pass a severance tax, with agreement from the governor, who believed that it would stifle investment in shale gas.[216] The legislature finally agreed upon an impact fee, but by February 2012, when the fee was enacted,[217] the state had issued approximately 10,248 permits for unconventional wells.[218] While the absence of a severance tax might not have impacted the pace of drilling and fracturing—many other factors, including deadlines in leases and the price of gas, often impact the speed at which new wells are developed—the lack of a tax might have provided marginal motivation for some operators.

G.C.M. 22730, 1941-1 C.B. 214); Walter D. Schwidetzky, *The Pool of Capital Doctrine: A Peace Proposal*, 61 TUL. L. REV. 519, 526 (1987) (describing the "much celebrated, highly abstruse and syntactically bizarre General Counsel Memorandum (GCM) 22730" as "arguably the most authoritative General Counsel Memorandum ever issued"). The pool of capital doctrine is liable to criticism for "creat[ing] an incentive for in-kind compensation and a disincentive for normal equity financing." Gergen, *supra*, at 539; *cf. id.* at 539 n.56 (characterizing the "subsidy argument" for the pool of capital doctrine as "preposterous because even if we wanted to subsidize oil and gas ventures through the [Internal Revenue] Code, it is absurd to do that by not recognizing gains from exchanges of labor for capital," rather than "by making [oil and gas] returns tax exempt or by providing a deduction for the cost of such investments").

214 *See, e.g.*, Susan Combs, Texas Comptroller of Public Accounts, Government Financial Subsidies 21 ("The *High-Cost Gas* program provides a tax incentive for high-cost gas wells based on the ratio of each well's drilling and completion costs to twice the median cost for all high-cost Texas gas wells submitted in the prior fiscal year.").

215 *Id*.

216 Susan Phillips, *Corbett Defends Impact Fee Over Severance Tax*, NATL. PUBLIC RADIO, June 14, 2013, http://stateimpact.npr.org/pennsylvania/2013/06/14/corbett-defends-impact-fee-over-severance-tax/.

217 Pa. Act 13, enacted Feb. 14, 2012.

218 Penn. Dep't of Envtl. Protection, Year to Date – Permits Issued by County and Well Type Report, http://www.depreportingservices.state.pa.us/ReportServer/Pages/ReportViewer.aspx?/Oil_Gas/Permits_Issued_Count_by_Well_Type_YTD (enter 1/1/2001 for PERMITS ISSUED START DATE, 2/14/2012 for PERMITS ISSUED END DATE, and select "Yes" for UNCONVENTIONAL ONLY).

C. REGULATORY RELIEF

Regulations, like taxes, might only impact development on the margins, assuming that governments do not ban gas development or impose unusually onerous restrictions on it. As an example of the potential relation between expenses of regulatory compliance and other development costs, when Pennsylvania's Department of Environmental Protection implemented rules required by the state's Act 13, which included enhanced environmental protections for hydraulically fractured wells like better secondary containment under tanks (to catch spills), larger setbacks between well sites and water resources, and a heightened presumption of fault for water pollution, it estimated that total compliance costs caused by the rulemaking would be "between $75,002,050 and $96,636,950 annually." Spread among approximately 1,751 Marcellus Shale wells drilled and fractured in 2011,[219] the estimated upper-bound cost would have been approximately $55,200 annually per well—an annual amount that is a small fraction of the $5 million that one unconventional well can cost although the total cost of regulatory compliance would rise, perhaps quite significantly, through annual accretion.

In any event, regulations, even those that arguably only hit margins, can be viewed as risking discouragement of development to a degree that policymakers find intolerable. This is evidenced by an EPA report that supported one of the first major exemptions for oil and gas development from federal environmental regulation.[220] In 1988, the Environmental Protection Agency determined that oil and gas "exploration and production" (E&P) wastes—most of the soil and rock cuttings, liquid wastes, used drilling fluids and muds, and other wastes found at well sites—should not be regulated as hazardous wastes under Subtitle C of the Resource Conservation and Recovery Act.[221] Congress, when writing RCRA, had not initially anticipated this exemption, but after heavy lobbying by the industry,[222] it directed the EPA to study these wastes and determine whether or not to regulate them.[223] The EPA noted in its report that some of the wastes had hazardous properties and had caused problematic pollution in a

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219 Penn. Dep't of Envtl. Protection, Bureau of Oil & Gas Mgmt., Wells Drilled, http://www.dep.state.pa.us/dep/deputate/minres/oilgas/2011%20Wells%20Drilled.gif.

220 Regulatory Determination for Oil and Gas and Geothermal Exploration, Development and Production Rates, 53 Fed. Reg. 25446, 25446 (July 6, 1988), http://epa.gov/osw/nonhaz/industrial/special/oil/og88wp.pdf.

221 53 Fed. Reg. 25,446-01, 25,447 (July 6, 1988).

222 James R. Cox, *Revisiting RCRA's Oilfield Waste Exemption as to Certain Hazardous Oilfield Exploration and Production Wastes*, 14 VILL. ENVTL. L.J. 1 (2003).

222 53 Fed. Reg. 25,446 (1988).

223 53 Fed. Reg. 25,446 (1988).

limited number of circumstances.[224] But it concluded that states and the federal government were, for the most part, doing a reasonable job of controlling the impacts of these wastes.[225]

The EPA also focused on the costs of regulatory compliance if the federal government were to treat the wastes as hazardous wastes under RCRA. The EPA studied three compliance cost scenarios—one with current waste management practices (which were primarily regulated by the states, as the EPA had not yet applied RCRA to oil and gas wastes), an "intermediate scenario" with "somewhat stricter controls on waste disposal," and a third, stringent scenario in which the wastes would receive full Subtitle C regulation.[226] Above the baseline scenario, "total annual costs for additional management requirements" in the intermediate scenario would have "ranged from approximately $50 million to over $6.7 billion," whereas the full regulatory scenario would have resulted in total annual costs between "$1 billion and $6.5 billion" over the baseline.[227] With 70,000 wells apparently in play, the average cost per well of such regulatory compliance might not have seemed so overwhelming,[228] but the EPA was apparently impressed. It ultimately exempted most oil and gas wastes from RCRA subtitle C regulation, thus ensuring that what was perceived as a potentially costly regulatory barrier would not impede well development.

The oil and gas industry, including the unconventional shale gas industry, benefited from other exemptions during its developmental stages. Congress did not hold operators liable for clean-up of land contamination under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) if these operators spilled petroleum substances, including natural gas, natural gas liquids, and liquefied natural gas, on the ground.[229] Oil companies, though, still faced Clean Water Act liability and, as of 1990, Oil Pollution Act liability for onshore spills.[230]

In further beneficial regulatory treatment, in the Energy Policy Act of 2005, Congress exempted all hydraulic fracturing, with the exception of fracturing that uses diesel fuel, from the definition of "underground

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[224] Envtl. Protection Agency, *supra* note 220, at 25455 ("EPA has documented 62 damage cases caused by crude oil and natural gas wastes.").
[225] Envtl. Protection Agency, *supra* note 220, at 25446.
[226] Envtl. Protection Agency, *supra* note 220, at 25449-254450.
[227] Envtl. Protection Agency, *supra* note 220, at 25450.
[228] These numbers were based on an estimated 70,000 "crude oil and natural gas wells" and additional wastes from geothermal energy wells. Envtl. Protection Agency, *supra* note 220, at 25448.
[229] 42 U.S.C. § 9601 (14).
[230] 40 C.F.R. 112.1.

injection" under the Safe Drinking Water Act.[231] As a result, fracturing could occur without a permit that would have required the operator to show that the process would not endanger underground sources of drinking water.[232]

Also in 2005, Congress attempted to narrow the Clean Water Act "stormwater" permitting required for the construction of oil and gas well sites—a permitting process intended to reduce soil erosion from sites.[233] A federal court case largely pushed back EPA's efforts to implement this exemption,[234] although some confusion remains as to which well sites require stormwater permits.[235]

These and other exemptions might have helped to spur both early-stage innovation relating to unconventional gas resources and also the ultimate shale gas boom, but the wisdom of this policy lever of regulatory relief has been questioned because of its potentially large costs—some of which are yet undetermined. There have been large spills of fracturing and drilling materials at well sites,[236] and some have polluted water resources.[237]

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[231] 42 U.S.C. § 300h (d)(1).

[232] *See supra* text accompanying notes __.

[233] 33 U.S.C. § 1362(24).

[234] Natural Res. Defense Council v. U.S. EPA, 526 F.3d 591, 594 (9th Cir. 2008).

[235] *See Regulation of Oil and Gas Production Activities*, EPA (Mar. 9, 2009) http://cfpub.epa.gov/npdes/stormwater/oilgas.cfm (attempting to clarify the regulation).

[236] *See, e.g.*, Maryland Attorney General, AG Gansler Secures Funding to Safeguard Susquehanna Water Quality, June 14, 2012, http://www.oag.state.md.us/Press/2012/061412.html ("During the gas well blowout near Leroy Township in Bradford County, Pennsylvania, fracking fluids escaped containment, crossed over neighboring farm fields, and entered into a tributary of Towanda Creek."); Agency for Toxic Substances & Disease Registry, ASTRD Leroy Township report finds elevated water well chemicals – Exact cause of elevated levels unclear, Nov. 7, 2011 ("The Agency for Toxic Substances and Disease Registry (ATSDR) investigated the water quality of seven residential wells surrounding the Chesapeake ATGAS 2H natural gas well site in Leroy Township, Bradford County, Pa., at the request of the U. S. Environmental Protection Agency (EPA) following a well blowout. ATSDR found that several wells had elevated levels of salts and other chemicals, according to a report released today."); Daniel J. Rozell & Sheldon J. Reaven, *Water Pollution Risk Associated with Natural Gas Extraction from the Marcellus Shale*, 32 RISK ANALYSIS 1382, 1384 (2011), http://onlinelibrary.wiley.com/doi/10.1111/j.1539-6924.2011.01757.x/pdf (finding that spills in the Marcellus could, over time, contaminate water that, volume-wise, would fill "a few thousand Olympic-sized swimming pools").

[237] *See, e.g.*, Maryland Attorney General, AG Gansler Secures Funding to Safeguard Susquehanna Water Quality, June 14, 2012, http://www.oag.state.md.us/Press/2012/061412.html (describing a well blowout during fracturing that sent fracturing fluids into an interstate waterway); Wiseman, *Risk and Response*, *supra* note 6, at 766-768, 799-801 (describing spills at well sites, including spills that entered swamps and other waters, based on state inspection reports).

Moreover, disposal wells that accept liquid wastes from drilling and fracturing have been associated with earthquakes in several regions—a problem known long before slickwater fracturing boomed, but one that could expand as well numbers rise.[238] Disposal wells are regulated under the Safe Drinking Water Act—which, in many states, is implemented by state environmental agencies—but the Act does not cover induced seismicity,[239] and only Arkansas[240] and Ohio[241] have changed their regulations to address this gap.

Drilling and fracturing also emit air pollution. This can exacerbate smog problems[242] or concerns about greenhouse gases. Gas wells and associated equipment leak methane, a potent greenhouse gas.[243] EPA Clean Air Act regulations that will be effective on January 1, 2015, require operators to capture volatile organic compounds (including methane) that are emitted during the flowback process, and some VOC emissions from associated equipment,[244] but these regulations do not cover many of the phases of drilling and gas transport that can leak methane.

Finally, communities that have become hosts to booming natural gas production have experienced a variety of more quotidian costs. These include road damage and traffic, increased demand for physical infrastructure and city services like fire and emergency response, changes in

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[238] Cliff Frohlich et al., *The Dallas-Fort Worth Earthquake Sequence: October 2008 through May 2009*, 101 BULL. SEISMOLOGICAL SOC'Y AM. 327 (2011), http://www.bssaonline.org/content/101/1/327.full.pdf+html; Austin Holland, Oklahoma Geological Survey, Potential for Induced Seismicity within Oklahoma at 6, Jan. 23, 2013 presentation, http://www.gwpc.org/sites/default/files/event-sessions/Holland_AustinFINAL.pdf.

[239] Envtl. Protection Agency, Minimizing and Managing Potential Impacts of Induced-Seismicity from Class II Wells: Practical Approaches, Nov. 2012, http://www.eenews.net/assets/2013/07/19/document_ew_01.pdf (studying the problem but not regulating it).

[240] Arkansas Oil & Gas Commission, Permanent Disposal Well Moratorium Area, http://www.aogc.state.ar.us/notices/Ex.%201B%20-Permanent%20Disposal%20Well%20Moratorium%20Area.pdf.

[241] OAC 1501:9-3-07 (Westlaw 2014).

[242] *See* N.Y. DEPT. OF ENVTL. CONSERVATION, SUPPLEMENTAL REVISED DRAFT ENVIRONMENTAL IMPACT STATEMENT at 6-187-188 (2011) (describing N_2O and carbon dioxide emissions from combustion at well sites).

[243] David T. Allen et al., *Measurements of Methane Emissions at Natural Gas Production Sites in the United States*, 110 PROC. NAT'L ACAD. SCI. 17768, 17769 (2013), http://www.pnas.org/content/early/2013/09/10/1304880110.full.pdf; Ramón A. Alvarez et al., *Greater Focus Needed on Methane Leakage from Natural Gas Infrastructure*, 109 PROC. NAT'L ACAD. SCI. 6435, 6438 (2012).

[244] 40 CFR § 60.5375 (Westlaw 2014).

historic economic activities like tourism and agriculture, and nuisances from the noise, light, dust, and pollution at well sites.[245]

Although it has not been shown that the environmental costs of unconventional gas development outweigh the large economic (and some environmental) benefits, no national cost-benefit analysis has yet been conducted to confirm this.[246] With unconventional natural gas now established as a booming industry, investment in some such assessment seems justified. Even if regulatory relief that favored the development of an "infant" unconventional gas industry ranks as a historic good, such relief might not be appropriate now that this energy sector has grown vastly in scope and revenue.

V. INTELLECTUAL PROPERTY, COMPLEMENTARY ASSETS, AND SHARING

A. COMPLEMENTARY ASSETS AND THE "NO PATENTS" STORY

As described in the Introduction, a common part of the origin story of the shale boom is that its beginnings were fundamentally patent-free. The key entrepreneur, Mitchell, and his successor, Devon Energy, did not patent key breakthroughs in slickwater fracturing and horizontal drilling.[247] The resulting lack of patent protection might have facilitated the subsequent shale gas boom, enabling others rapidly to copy Mitchell and Devon's

[245] Susan Christopherson & Ned Rightor, The Boom-Bust Cycle of Shale Gas Extraction Economies, Community & Regional Development Institute, Dept. of Development Sociology, Cornell University, CARDI Reports Issue 14, Sept. 2011, at 4, http://www.greenchoices.cornell.edu/downloads/development/shale/Economic_Consequences.pdf; Jacquet et al., Energy Boomtowns and Natural Gas: Implications for Marcellus Shale Local Governments & Rural Communities, NERCRD Rural Development Paper No. 43, Jan. 2009, aese.psu.edu/nercrd/publications/rdp/rdp43/at_download/file; CJ Randall, Hammer Down: A Guide to Protecting Local Roads Impacted by Shale Gas Drilling, Dec. 2010, at 2, http://www.greenchoices.cornell.edu/downloads/development/shale/Protecting_Local_Roads.pdf; Williston Impact Statement 2012, http://www.willistondevelopment.com/usrimages/Williston_Impact_Statement.pdf.

[246] Reports commissioned by the DOE concluded that natural gas exports are in the public interest, but it did not conduct a nationwide analysis of all costs and benefits of all unconventional gas development. Energy Info. Admin, Effects of Increased Natural Gas Exports on Domestic Energy Markets (Jan. 2012); NERA Economic Consulting, Macroeconomic Impacts of LNG Exports from the United States (2012), http://energy.gov/sites/prod/files/2013/04/f0/nera_lng_report.pdf.

[247] Cahoy, Gehman & Lei, *supra* note __, at 291 ("[D]uring the late 1990s and early 2000s, neither Mitchell nor Devon pursued patent protection for their respective innovations in slickwater hydraulic fracturing and horizontal drilling.").

techniques without having to pay licensing fees or worry about lawsuits for patent infringement.[248]

There is plausibility to the basic "no patent" story—really a "no patent" and "no trade secret" story to the extent it suggests that information about advances such as those by Mitchell Energy was freely circulated for others to use. A major source of plausibility for this story comes from the fact that, without obtaining patents or keeping certain forms of key information secret, companies like Mitchell Energy and Devon Energy could use investments in complementary assets—private land and mineral rights—to appropriate very substantial returns from innovation.[249]

Mitchell Energy itself provided a classic example of how to appropriate value from innovation by acquiring substantial land and mineral rights in the Barnett Shale at a time when prices were relatively low. After Mitchell had greatly increased the value of those rights by developing and publicizing such advances as slickwater fracturing, Mitchell was able to sell those rights high.[250]

Mitchell pursued this strategy of buying low and selling high quite deliberately. In the late 1980s Mitchell Energy apparently delayed joining forces with GRI because of concern that such collaboration would draw too much attention and thereby drive up prices for rights to land and minerals in the Barnett Shale.[251] In the 1990s, after Mitchell Energy had improved "its acreage position," it began working with GRI and ultimately made the key breakthroughs that it publicized in the early 2000s.[252] In 2002, Mitchell reaped the rewards: having proven the Barnett Shale's profitability, Mitchell sold itself and its carefully acquired land and mineral rights to Devon Energy for $3.5 billion.[253]

Other early movers mimicked Mitchell's success. Range Resources– the first successful developer of a Marcellus Shale well in Appalachia, snapped up land and mineral rights in southwestern Pennsylvania and its

[248] *Id.*
[249] Wang & Krupnick, *supra* note 11, at 30 ("Private land ownership contributed to the development of shale gas in that it offered entrepreneurial natural gas firms a method of obtaining reasonable returns form their early investments.").
[250] *See infra* text accompanying notes 251-253.
[251] Wang & Krupnick, *supra* note 11, at 18 (noting that, in the late 1980s, "Mitchell Energy was in the process of acquiring leases on large tracts of land, so George Mitchell was, according to Steward (2007, p. 91), 'concerned that any unnecessary publicity might adversely affect the growth of [the firm's] acreage position'").
[252] *Id.*
[253] *See supra* text accompanying note 94.

environs. [254] "By August 2007, Range had spent more than $150 million on what it described to its investors as its 'Appalachian Basin Devonian shale gas play—a sizeable investment for a company that had a market capitalization of $400 million."[255] When prices for gas rights "climbed from about $50 to thousands of dollars per acre at the height of the leasing frenzy in 2008 and 2009," Range's value swelled as well: within a few years, the $400-million-dollar company was worth $8 billion.[256]

Consequently, in the case of the shale gas boom, there is no mystery about how private firms could share basic information on new techniques for gas extraction while still hoping that their large capital investments would yield handsome profits. In Jonathan Barnett's terms, state-backed land and mineral rights provided the supplemental means for appropriation—the background "access limitations"[257]—that underwrote the firms' capital investments and thus enabled a regime of information sharing with limited reliance on intellectual property.[258]

Indeed, the quick and geographically widespread adoption of the "Mitchell synthesis" by a host of independent producers highlights an aspect of complementary assets in land and minerals that contrasts with the nature of intangible intellectual property. The spatially limited nature of typical "real world" land and mineral leases plus the generally self-limiting nature of processes for their acquisition can make difficult and even impractical the effective "monopolization" of an extraction technology through purchase of leases covering all relevant deposits. Hence, even while enabling large rewards for innovators such as Mitchell, reliance on land and mineral leases as the primary means for appropriating innovation's value helped ensure that rewards were less than fully exclusionary with respect to the activity of shale gas extraction. Further, reliance on land and mineral leases helped ensure that rewards were proportional to at least one dimension of the cost and risk that a would-be innovator had taken on.

This generally self-limiting character of private land and mineral leases as a mechanism for appropriation contrasts with the typically easily

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[254] Jonathan D. Silver, *The Marcellus Boom/Origins: the story of a professor, a gas driller and Wall Street*, PITT. POST-GAZETTE, Mar. 20, 2011, at __.

[255] Cahoy et al, *supra* note __, at 287.

[256] Silver, *supra* note 254, at __.

[257] Jonathan M. Barnett, *The Illusion of the Commons*, 25 BERKELEY TECH. L.J. 1751, 1754 (2010) (contending that "economically significant levels of innovation investment almost never appear without some form of property rights or other access limitations").

[258] *Id.* at 1814 (arguing for the proposition that, "[a]t least in innovation settings that demand substantial capital investments, … sharing regimes … are unlikely to persist unless supplemented by state-provided property rights or some other exclusionary mechanism of functional equivalence").

extensive nature of disembodied intellectual property rights. Based on a stroke of the legislative pen, property rights such as patents can claim exclusionary effect across entire countries, and, at least partly as a result of several strokes of a patent applicant's pen, a patent can have a substantive breadth bearing little necessary proportion to the attorney fees and filing costs that constitute its direct expenses of acquisition. These elements of contrast between land and mineral rights and intellectual property rights suggest that the relatively natural spatial limitations on privately held land and mineral rights can, under appropriate circumstances, make them particularly fit to support a regime of decentralized development and exploitation by nimble, independent actors such as those who rapidly spread implementation of the Mitchell synthesis.

B. INFORMATION SHARING

Of course, the ability of companies like Mitchell to make profits without patenting key innovations does not necessarily explain their failure to seek patent protection. If Mitchell had obtained patent rights relating to slickwater hydraulic fracturing, Mitchell might have made even more money, supplementing through patent royalties the amounts earned from an increase in the value of its lease rights in the Barnett Shale. Why would it not seek to do so?

One reason might be that Mitchell believed that patent rights were unavailable. Hydraulic fracturing using water, rather than relying more substantially on fancier foams or gels, had long been known as a technique for increasing fossil fuel recovery. Mitchell might have believed that, given this pre-existing public knowledge, Mitchell's adaptation of the technique to the peculiarities of the Barnett Shale would not support a patent or, at least, would not support a patent having enough breadth to cover the particular fracturing techniques that other operators would find optimal for other formations or perhaps even other parts of the Barnett Shale. Indeed, there seems to be some impression that, in the business of fossil fuels extraction, "few technologies are patentable."[259]

But the posited assumption that patents were unavailable seems to be a misapprehension decisively belied by the fact that the U.S. Patent and Trademark Office has issued scores of patents relating to the technologies of hydraulic fracturing and directional drilling over the course of decades.[260]

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[259] Wang & Krupnick, *supra* note 249, at 17-18 ("Since few innovations are patentable and licensable and it is difficult to keep innovations proprietary, the best way to obtain financial reward from R&D investments in the natural gas industry is through leasing large tracts of land that can be sold at higher prices later.").

[260] *See infra* text accompanying notes __.

Although Mitchell Energy, Devon Energy, and other players in the early stages of shale gas development were generally independents,[261] they were not necessarily unsophisticated. "By the time Mitchell Energy drilled the first Barnett well in 1981, it was the largest gas producer in North Texas and a diversified, publicly traded company whose business included not only the exploration, production, gathering, and processing of natural gas, but also drilling rigs and real estate operations."[262] Further, Mitchell Energy was familiar with the possibility of obtaining a parent for a novel variation on or adjunct to a previously developed technique: in the 1980s, Mitchell Energy Corporation obtained two patents on processes relating to previously developed fluid-injection techniques in which a fluid such as water is injected into a formation to force oil in the formation toward a well.[263] Thus, it seems unlikely that Mitchell refrained from patenting its improvements on previously developed techniques of hydraulic fracturing as a result of very straightforward mistakes about patent rights' potential availability.

A more likely explanation is that an operator like Mitchell believed that pursuing patent rights simply was not worth the trouble, perhaps because of a combination of (1) open-access requirements resulting from their collaboration with GRI or from other, state-imposed rules, and (2) difficulties in enforcing patent rights on processes of extraction that might commonly be conducted in relatively isolated locations, out of plain sight, and even deep underground. Indeed, partnerships such as those Mitchell had with GRI apparently triggered requirements of "full publication of findings" and surrender of claims to intellectual property in those findings.[264] And GRI's fundamental nature as a gathering point for collaborative effort and discussion perhaps more generally helped foster a culture focused on information exchange over pursuit of intellectual property rights, perhaps in part because FERC, GRI's sponsor, rendered GRI "indifferent to [potential intellectual property] royalties by subtracting any royalties from FERC funding," thereby "ensur[ing] that GRI focused on technology diffusion as much as possible."[265] The independent companies pursuing shale gas development might have been particularly likely to

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[261] *See* Wang & Krupnick, *supra* note 249, at 31 ("The major oil firms, which are much larger than any independent natural gas firm, had the capacity [for large investments], but they did not invest in shale gas early.").

[262] *Id.*

[263] U.S. Pat. No. 4,742,873 (issued May 10, 1988) (listing Mitchell Energy Corp. of the Woodlands, Texas, as the assignee); U.S. Pat. No. 4,291,765 (issued Sept. 29, 1981) (listing Mitchell Energy Corp. of Houston, Texas, as the assignee).

[264] BURWEN & FLEGAL, *supra* note 53, at 36.

[265] *Id.*

welcome such a culture of information sharing as an informal means to join in a cooperative R&D venture in a situation where few, if any, had the resources to make the key breakthroughs on their own.

Notably, the apparently successful model for federal support of shale gas innovation through GRI appears to have contrasted markedly in its approach to intellectual property rights with the nearly contemporaneously adopted "Bayh-Dole model" for federally supported science and engineering research at universities. Under the Bayh-Dole Act, universities were encouraged to seek patents in the products of federally funded research and then to use these patents as levers for commercialization of the results of that research, often through exclusive licenses.[266] Whether the Bayh-Dole Act adopted an optimal approach is controversial,[267] but there can be little doubt that the Act has fostered an environment in which universities and their technology transfer offices look increasingly to make money through obtaining and enforcing patent rights[268]—a course of conduct that perhaps ironically seems more proprietary and exclusionary than that nurtured by GRI.

In any event, information-sharing requirements and cultural norms fostered by GRI appear not to have been the only reasons supporting information sharing or a failure to pursue patent rights. Certain key information effectively had to be shared. Under regulations applicable in most of North America, firms had to "reveal fracturing and production-performance data within 6 months following execution."[269] In a world in which simply developing information about the possibilities for fracturing and resource recovery from a particular rock formation often demanded huge capital investments, competitors could be expected to "plunder [such data] for insight."[270] Instead of complaining that other prospectors were free-riding, members of the relevant industrial community seem to have accepted the fact that such information would circulate and designed their business models accordingly. It probably aided such acceptance that, as

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[266] John M. Golden, *Biotechnology, Technology Policy, and Patentability: Natural Products and Invention in the American System*, 50 EMORY L.J. 101, 120 (2001) ("The Bayh-Dole Act … sought to stimulate … technology transfer by allowing government grantees and contractors to patent inventions and to sell exclusive licenses for their use.").

[267] Arti K. Rai & Rebecca S. Eisenberg, *Bayh-Dole Reform and the Progress of Biomedicine*, 66 L. & CONTEMP. PROBS., winter/spring, 2003, at 289, 291 (contending that university patenting under the Bayh-Dole Act might "hinder rather than accelerate biomedical research").

[268] *Id.* (describing a "frenzy of proprietary claiming" by universities under the Bayh-Dole Act).

[269] Beckwith, *supra* note __, at 36.

[270] *Id.*

suggested by Mitchell's story,[271] as long as a firm had made sufficient advance purchases of land and mineral rights, circulation of credible information about successful fracturing and well development could work to an early prospector's substantial favor. Copycats inspired by such disclosures could drive up the value of the early mover's land and mineral rights by seeking to buy their way into a winning play.

Moreover, information sharing might have been partly embraced because of a sense of its inevitability in an industry where producers typically relied on various specialized service companies to drill and fracture wells. These service companies, whose ranks today are headed by multinational firms such as Halliburton Co. and Schlumberger Ltd.,[272] acted as natural cross-pollinators of techniques and geological information as they moved from job to job and company to company, with tight restriction of resulting transfers of knowledge presumably being difficult—and perhaps even being privately undesirable.[273]

A final, perhaps decisive point is that natural gas producers were looking to generate a commodity. Their innovations, anything they could patent, would presumably tend not to be in the end products that they sought to sell publicly, but instead in the privately deployed processes that they used to extract and deliver to market a commodity, natural gas. There would, of course, be new devices such as downhole motors for drills that would play important roles in the implementation such processes, but even a large independent such as Mitchell Energy appears not to have played a substantial role in the development or commercialization of such supporting products. The main form of innovations by a company like Mitchell Energy would seem likely to have been process innovations, perhaps involving particular ways of carrying out hydraulic fracturing or directional drilling to match the peculiarities of a specific formation. Patents on process innovations of this sort—process innovations used privately to generate a distinct good for public consumption—have long been appreciated to be generally more difficult to enforce than patents on consumer goods themselves.[274] The fact that the hydraulic fracturing and drilling processes

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[271] *See supra* text accompanying notes __.

[272] *See* Halliburton, Corporate Profile, http://www.halliburton.com/en-US/about-us/corporate-profile/default.page?node-id=hgeyxt5p; Schlumberger, Multistage Fracturing Services, http://www.slb.com/services/completions/stimulation/reservoir/contact.aspx.

[273] NAT'L RESEARCH COUNCIL, *supra* note 37, at 55 ("[M]any projects in the drilling, completion, and stimulation (DCS) areas are very risky and difficult for any one company to keep proprietary since they are often implemented by service companies.").

[274] *See, e.g.*, Ted Sichelman & Stuart J.H. Graham, *Patenting by Entrepreneurs: An Empirical Study*, 17 MICH. TELECOMM. & TECH. L. REV. 111, 176 (2010) ("[A]ll else being equal, one would expect that process patents are more difficult to litigate, because of

in question were not only used privately but also typically performed for only limited times at scattered geographic locations and commonly performed substantially underground—perhaps a mile or so underground—presumably made the prospects for enforcement seem even less auspicious than in many other fields.

In short, general difficulties with policing infringement of process-patent violations might have combined with the overall regulatory environment and the difficulty of controlling information circulation by service companies to make pursuit of a "patent strategy" relatively undesirable. Scarce funds in the years before the shale gas boom might have been best spent in doing a better job with a mainline strategy of investing effectively in complementary assets and using all available information, including information obtained from other companies, to maximize those assets' value. Failure to patent one's own innovations and willingness to share certain kinds of information might have helped ensure the continuation of a regime of significant information sharing and relatively open access to new techniques from which all the players involved would have opportunity to benefit.[275]

C. TRADE SECRETS AND NON-KITCHIAN PATENTS

Despite the unconventional natural gas industry's being structured in many ways that favored information sharing and fast technology dispersion,[276] characterization of the area as an "IP-free" or "negative IP" zone[277] would be mistaken. Although broad swaths of information apparently circulated relatively freely, players in the unconventional natural gas industry have long kept or tried to keep some forms of information as trade secrets. Further, patents on aspects of hydraulic fracturing, directional

problems proving infringement."); Rebecca S. Eisenberg, *Technology Transfer and the Genome Project: Problems with Patenting Research Tools*, 5 RISK: HEALTH, SAFETY & ENV'T 163, 169 (1994) (noting that a patent on a manufacturing process can be "less effective" than on a marketed "end product" "because of practical problems in detecting and proving infringing activities in the manufacturing process that are not apparent from inspection of the end product").

[275] *Cf.* Brett M. Frischmann & Mark A. Lemley, *Spillovers*, 107 COLUM. L. REV. 257, 270 (2007) (suggesting how an environment favoring information "spillovers" can generally benefit industry members through the example of Silicon Valley's flourishing "in significant part because employees and knowledge moved freely to new companies").

[276] *Cf.* NAT'L RESEARCH COUNCIL, *supra* note 37, at 55.

[277] *Cf.* Kal Raustiala & Christopher Sprigman, *The Piracy Paradox: Innovation and Intellectual Property in Fashion Design*, 92 VA. L. REV. 1687, 1764 (2006) (describing the fashion industry as "part of IP's 'negative space'" because it "is a substantial area of creativity into which copyright and patent do not penetrate and for which trademark provides only very limited propertization").

drilling, or associated technologies have long been a feature of various lines of innovation that converged to produce the shale gas boom.

Generally speaking, there is some schizophrenia in accounts of information flows in the oil and gas industry. As indicated above, the ease of information flow and difficulties in controlling that flow are often emphasized.[278] On the other hand, there are statements indicating that not all information is shared. For example, in emphasizing the value of federal R&D support for smaller independents, Jason Burwen and Jane Flegal explain that "[m]ajor companies in the industry tend to guard knowledge of their own innovations as competitive advantages."[279] Indeed, the fact that processes often occur miles below ground might make patents difficult to enforce, but it also might make secrecy easier. Firms have regularly entered into consortia that conduct seismic testing and mapping of shales—complex processes that rely on data captured from far beneath the earth's surface—with an accompanying agreement that the data will not be shared beyond the consortium. Perhaps even more tellingly, firms involved in hydraulic fracturing have long fought against requirements that they disclose details of the chemical mixtures used on grounds that those details are commercially valuable trade secrets.[280] Whether the "regulatory cost" of disclosure to the public, as opposed to the "competitive cost" of disclosure to other producers, is decisive in motivating the holding of these secrets might be an open question. For purposes here, however, the most relevant point is that, although much information flows relatively freely in the unconventional natural gas industry, there is a residuum of information that individual players try to hold as their own.

Trade secrecy is not the only way by which companies have sought proprietary control over technical innovations. One set of commentators has suggested that, as demands for disclosure of the details of chemical mixtures used in fracking have increased, firms have increasingly obtained patents on these mixtures, presumably because the reality or prospect of forced disclosure has rendered trade secrecy a nonviable option.[281] Regardless of whether this is true, patents have essentially always been present with respect to key technologies that undergird the shale gas boom.

[278] *See supra* notes __ and accompanying test.
[279] BURWEN & FLEGAL, *supra* note 53, at 5.
[280] *See supra* note 29 and accompanying text.
[281] Cahoy, Gehman & Lei, *supra* note __, at 283 ("Simply put, given the demand for disclosure, companies could be paradoxically pursuing patenting in part as a means of information containment."); *see also id.* at 290-291 ("[F]racturing fluids are the apparent reason for the increase in patent activity in the gas extraction industry.").

In the mid-twentieth century, patent protection went hand in hand with the early stages of hydraulic fracturing's development. As discussed in Part I, in 1947 Stanolind Oil and Gas Corporation engaged in the first experiment with hydraulic fracturing.[282] By 1948, Stanolind, through named inventors Joseph Clark, Riley Farris, and G.C. Howard, had begun obtaining a series of patents on hydraulic fracturing processes.[283] Soon after these patents issued, Stanolind licensed them to a service company, Halliburton Oil Well Cementing Co.[284] Monetization of patent rights was not unknown. In 1953, the companies agreed that Halliburton's license would be nonexclusive but that Halliburton would be compensated for this nonexclusivity by receiving one third of royalties received under Stanolind's licenses with others.[285]

Stanolind was not the only company obtaining patents in the area. Even with only a little searching, one can find multiple patents on hydraulic fracturing processes that issued from the 1950s through the 1990s. The original assignees of such patents include major companies or major-company affiliates such as Atlantic Richfield Company,[286] the Dow Chemical Co.,[287] Esso Production Research Co.,[288] Mobil Oil Corp.,[289] Pan American Petroleum Corp.,[290] and Standard Oil Development Co.[291] Some

[282] Montgomery & Smith, *supra* note __, at 27.
[283] *E.g.*, U.S. Pat. No. 2,667,224 (issued Jan. 26, 1954) (entitled "Well Completion Process" and showing a filing date of June 29, 1949); U.S. Pat. No. 2,596,845 (issued May 13, 1952) (entitled "Treatment of Wells" and showing a filing date of May 28, 1948); U.S. Pat. No. 2,596,844 (issued May 13, 1952) (entitled "Treatment of Wells" and showing a filing date of Dec. 31, 1949); U.S. Pat. No. 2,596,843 (issued May 13, 1952) (entitled "Fracturing Formations in Wells" and showing a filing date of Dec. 31, 1949), reissued as U.S. Pat. Re. 23,733 (issued Nov. 10, 1953).
[284] Montgomery & Smith, *supra* note __, at 27.
[285] Cahoy, Gehman & Lei, *supra* note __, at 289.
[286] U.S. Pat. No. 5,054,554, col. 1, ll. 41-46 (issued Oct. 8, 1991) ("[A] fracturing method is provided wherein the rate of fluid injection is such as to control the growth of the fracture by packing proppant into the fracture tip to arrest fracture length increase and then increasing the width of the fracture by injecting higher concentrations of proppant.").
[287] U.S. Pat. No. 3,302,717, col. 8, ll. 11-13 (issued Feb. 7, 1967) (claiming a "method of fracturing a well penetrating a subterranean formation"); U.S. Pat. No. 3,181,612, col. 9, ll. 49-51 (issued May 4, 1965) (same).
[288] U.S. Pat. No. 3,378,074, col. 1, ll. 26-28 (issued Apr. 16, 1968) ("This invention relates to the hydraulic fracturing of subterranean formations surrounding oil wells, gas wells and similar boreholes.").
[289] U.S. Pat. No. 4,892,147, col. 4, l. 44 (issued Jan. 9, 1990) (claiming a "method for hydraulic fracturing a formation where a fused refractory proppant is used"); U.S. Pat. No. 3,858,658, col. 5, ll. 58-60 (issued Jan. 7, 1975) (claiming a "method of forming a vertical fracture in a thick subterranean formation").
[290] U.S. Pat. No. 2,986,213, col. 4, ll. 5-8 (issued May 30, 1961) (claiming a process "wherein quantities of a hydrocarbon liquid and blackstrap molasses are alternately

patents relating to hydraulic fracturing issued to less prominent assignees, including individual inventors[292] or companies such as California Research Corp.[293] and Intercomp Resource Development and Engineering, Inc.[294]

The multiple technological aspects of fracking processes offered ample opportunities for associated sub-innovations. Almost immediately, patents were being obtained on mere parts of hydraulic fracturing processes or on materials and devices associated with such processes. Thus, as early as 1951, Sinclair Oil obtained a patent on a "process for breaking soap thickened petroleum gels"[295] used in fracturing, the point being that breaking down the gels would enable readier removal of fracking fluid from the formation.[296] Likewise, in 1952, Stanolind obtained a further patent on "an improved composition of matter," "an oil-in-water emulsion which is particularly adapted to be used in the Hydrafrac process."[297] In the decades leading up to Mitchell's late 1990s breakthrough, companies and individuals obtained additional patents that involved any of a variety of specified fracking-related details, devices, components, or sub-techniques: for example, specific forms of proppants,[298] gels,[299] "gel breakers,"[300]

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injected into said well at a rate sufficient to extend a fracture into said formation"); U.S. Pat. No. 2,838,117, col. 1, ll. 17-20 (issued June 10, 1958) (describing "an improvement in hydraulic fracturing processes wherein the fractures may be produced at selected elevations").

[291] U.S. Pat. No. 2,547,778, col. 1, ll. 1-5 (issued Apr. 3, 1951) ("This invention relates to a process for treating earth formations to increase the production of fluids therefrom and particularly to a process for lifting and fracturing or 'breaking down' earth formations.").

[292] *E.g.*, U.S. Pat. No. 2,927,638, col. 1, ll. 14-16 (issued Mar. 8, 1960) ("This invention relates to improvements in the fracturing of the earth formation surrounding wells …."); U.S. Pat. No. 2,915,122, col. 1, ll. 17-20 ("This invention particularly relates to an improved method for hydraulically fracturing … underground formations ….").

[293] U.S. Pat. No. 2,859,821, col. 5, ll. 26-29 (issued Nov. 11, 1958) (claiming a "method for increasing the productivity of a subterranean formation penetrated by a well by hydraulic fracturing").

[294] U.S. Pat. No. 3,933,205, col. 1, ll. 21-25 (issued Jan. 20, 1976) ("This invention relates to hydraulic fracturing of earth formations, and more particularly to the hydraulic fracturing of HC (hydrocarbon) bearing formations, e.g. oil and gas sands ….").

[295] U.S. Pat. No. 2,652,370, col. 4, ll. 20-22 (issued Sept. 15, 1953).

[296] *Id.* at col. 1, ll. 16-19.

[297] U.S. Pat. No. 2,742,426, col. 1, ll. 11-15 (issued Apr. 17, 1956).

[298] U.S. Pat. No. 4,892,147, col. 2, ll. 5-7 (issued Jan. 9, 1990) ("This invention relates to a method for hydraulic fracturing a formation where a fused refractory proppant is utilized."); U.S. Pat. No. 3,888,311, col. 1, ll. 50-55 (issued June 10, 1975) ("In the method of the present invention, a fracture generated in a subterranean formation by … hydraulic force is propped with … cement pellets or cement clinker particles."); U.S. Pat. No. 3,708,560, col. 2, ll. 12-21 (issued Jan. 2, 1973) (describing "object[s] of the present invention" as including provision of proppants with specified properties such as "compressive toughness," "freedom from brittleness," and "uniform configuration").

fracking-fluid mixtures,[301] approaches to generating holes in well casings through which fracking fluid can exert pressure on the surrounding rock,[302] methods for seismic imaging of induced fractures,[303] and "measurement of delayed gamma rays" to determine the distribution of proppant within a formation.[304]

In the past several decades, patents on techniques and devices relating to directional drilling appear to have been a similarly constant companion of technological development. At least since the early 1920s, there were patent claims relating to deflected drilling using a whipstock[305] and even for a technique of drilling a horizontal hole using a guide pipe with a vertical-to-horizontal elbow.[306] By the 1980s, there seems to have been a drumbeat of issued patents relating to modern techniques of directional drilling using

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299 U.S. Pat. No. 4,779,680, col. 2, ll. 11-14 (issued Oct. 25, 1988) ("The gel employed in the fracturing process of the present invention comprises a polymer, an aqueous solvent, and a crosslinking agent."); U.S. Pat. No. 3,727,689, col. 2, ll. 6-11 (issued Apr. 17, 1973) ("The present invention provides methods of fracturing porous formations employing aqueous gels prepared by gelling solutions of certain polyacrylamides, and related polymers, as described further hereinafter.").

300 U.S. Pat. No. 3,163,219, col. 1, ll. 10-12 (issued Dec. 29, 1964) ("[T]his invention concerns delayed action gel breakers for borate-gum gels."); U.S. Pat. No. 2,774,740, col. 5, ll. 8-14 (issued Dec. 18, 1956) (claiming a "process for breaking of gels composed of polyvalent metal soap and a liquid hydrocarbon which comprises adding to said gel a chelating agent of the group consisting of beta-di-oxo compounds, 8 hydroxyquinoline, and orthohydroxy aromatic aldehydes").

301 U.S. Pat. No. 2,793,998, col. 1, ll. 14-17 ("[T]his invention pertains to a temporary oil-in-water emulsion which is particularly adapted to be used as a fracturing fluid in the Hydrafrac process.").

302 U.S. Pat. No. 5,564,499, col. 1, ll. 7-10 (issued Oct. 15, 1996) ("This invention relates to a method and apparatus for penetrating well casings and scoring the surrounding rock to facilitate hydraulic fractures.").

303 U.S. Pat. No. 3,739,871, col. 1, ll. 6-11 (issued June 19, 1973) (describing an invention "in the field of seismic mapping" "concerned with the problem of determining the position … of the fractures induced … by the application of high fluid pressures to the rock wall of the bore hole").

304 U.S. Pat. No. 4,926,940, col. 2, ll. 19-27 (issued May 22, 1990).

305 U.S. Pat. No. 2,586,662, col. 1, ll. 3-7 (issued Feb. 19, 1952) ("One object of the invention is to provide an improved apparatus for drilling an inclined or directional well which apparatus combines a core bit with a deflecting tool, such as a whipstock …."); U.S. Pat. No. 1,970,761, p. 1, ll. 1-3 (issued Aug. 21, 1934) ("This invention relates to the use of a whipstock whereby a bit is deflected from a course which it has previously pursued."); U.S. Pat. No. 1,454,048, p. 1, ll. 10-28 (issued May 8, 1923) (describing "an improvement in the process known, in the art of drilling oil wells, as 'side tracking'").

306 U.S. Pat. No. 1,367,042, p. 1, ll. 80-82 (issued Feb. 1, 1921) (describing how "an elbow" is attached to the end of a set of "rigid pipe sections").

downhole motors[307] or new approaches to monitoring drilling progress.[308] Initial assignees for these patents include service companies or suppliers for the oil and gas industry such as Halliburton Co.,[309] Maurer Engineering Inc.,[310] and Schlumberger Technology Corp,[311] but patent rights assigned to major producers were not unknown.[312]

In sum, far from being patent-free, the technological areas that converged to generate the technologies behind the shale gas boom appear to have been rife with patenting for decades. This conclusion is consistent with the sense of some commentators that, "[g]iven the globally competitive and cooperative landscape of energy technology development, patents are considered a core means of protecting innovation in the energy sector, as in other sectors."[313]

Nonetheless, despite their availability and actual presence, patents appear not to have played a major role in either stimulating or impeding the key set of final breakthroughs that opened U.S. shale formations to commercially lucrative exploitation on a grand scale.[314] At least when we focus on this part of the shale gas story, we do not find broad Kitchian "prospect patents" to have a prominent part either in launching the field or

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[307] *See*, *e.g.*, U.S. Pat. No. 4,811,798, col. 1, ll. 4-7 (issued Mar. 14, 1989) ("This invention pertains to the use of down hole well drilling motors … to accomplish either straight hole drilling or directional drilling …."); U.S. Pat. No. 4,492,276 (issued Jan. 8, 1985) ("The invention relates to a down-hole drilling motor and a method for directional drilling by means of said motor …."); U.S. Pat. No. 4,185,704, col. 1, ll. 58-61 (issued Jan. 29, 1980) (describing "new and useful improvements in apparatus for directional drilling" "particularly adapted to the use of in-hole drilling motors").

[308] *See*, *e.g.*, U.S. Pat. No. 5,160,925, col. 1, ll. 6-37 (issued Nov. 3, 1992) (describing the "present invention" as "relat[ing] to a measurement-while-drilling ('MWD') system that senses and transmits data measurements from the bottom of a downhole assembly," advantages of which could include "enhanc[ing] drilling control during directional drilling"); U.S. Pat. No. 5,139,094, col. 1, ll. 6-11 (issued Aug. 18, 1992) ("This invention relates generally to methods and apparatus combinations for controlling the direction of the drilling of a borehole, and particularly to the use of downhole adjustable tools and directional measurements ….").

[309] U.S. Pat. No. 5,332,048 (issued Feb. July 26, 1994) (listing Halliburton as the assignee); U.S. Pat. No. 5,086,850 (issued Feb. 11, 1992) (same).

[310] U.S. Pat. No. 4,991,668 (issued Feb. 12, 1991) (listing Maurer Engineering Inc. as the assignee); U.S. Pat. No. 4,185,704 (issued Jan. 29, 1980) (same).

[311] U.S. Pat. No. 5,311,952 (issued May 17, 1994) (listing Schlumberger Technology Corp. as the assignee).

[312] *See* U.S. Pat. No. 4,492,276 (issued Jan. 8, 1985) (listing Shell Oil Co. as the assignee).

[313] Kyungpo Lee & Sungjoo Lee, *Patterns of Technological Innovation and Evolution in the Energy Sector: A Patent-Based Approach*, 59 ENERGY POL'Y 415, 415 (2013).

[314] *See supra* text accompanying notes __.

in coordinating subsequent activity.[315] Instead, the federal government and its beneficiary, GRI, played vital coordinating roles,[316] and the prospect of vastly increased prices for complementary assets was the dominant stimulus.[317] Consistent with Robert Merges and Richard Nelson's general competition-based prescription for technological progress,[318] the competitiveness and relative nimbleness of independent gas producers drove rapid diffusion and adaptation of Mitchell Energy's key breakthroughs to a multitude of widely dispersed drilling sites.[319]

By contrast to the explosion of innovation that non-patent factors spurred, patents in this case appear to have played more of a quiet, background role. At least under an optimistic view of such intellectual property rights, their long-established presence in a variety of key technology areas suggests that they helped foster a slow, decades-long drip of often incremental innovation, one that gradually built up vast reservoirs of relevant technological capacity and knowhow.[320] But patents appear to have had relatively little to do with the critical break that unleashed the modern-day flood. The result is a story that, although not a truly "no patent" story, is still a tale that limits patents to a relatively humble role. Further, the story is one that that represents something of a counterexample—or exception—to theories that patents are particularly crucial to fostering disruptive, breakthrough innovation.[321] In the story of the shale gas boom, the ready availability of complementary assets that

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[315] *See* Kitch, *supra* note 30, at 267 (contending that "the scope accorded to patent claims, a scope that reaches well beyond what the reward function would require," is evidence of "[t]he importance of the prospect function in the American patent system"); *id.* at 276 (noting how "the patent owner [is] in a position to coordinate the search for technological and market enhancement of the patent's value")

[316] *See supra* text accompanying notes __.

[317] *See supra* text accompanying notes __.

[318] *See* Robert P. Merges & Richard R. Nelson, *On the Complex Economics of Patent Scope*, 90 COLUM. L. REV. 839, 908 (1990) ("Our general conclusion is that multiple and competitive sources of invention are socially preferable to a structure where there is only one or a few sources.").

[319] *See* Beckwith, *supra* note __, at 36 ("The development and application of hydraulic fracturing technology in the US has been driven by independents, with a low cost base and the critical mass necessary to learn and respond quickly to new developments in modeling, planning, fluids, and proppants technology.").

[320] *Cf.* John M. Golden, *Litigation in the Middle: The Context of Patent-Infringement Injunctions*, 92 TEX. L. REV. (forthcoming 2014) ("[M]uch of the work of the patent system might lie … in the fostering or frustrating of more innocuous technologies and the quiet, comparatively diffuse cumulation of social betterment to which they contribute.").

[321] *See* John M. Golden, *Patent Privateers: Private Enforcement's Historical Survivors*, 26 HARV. J.L. & TECH. 545, 595 (2013) (noting that an "oft hypothesized … purpose of patents is to provide a foothold for 'disruptive technologies' and upstart entrepreneurs").

could richly reward innovation—analogs of the very mineral rights that helped inspire Edmund Kitch's "prospect theory" for patents[322]—might explain why, in this case, patents appear to have been relegated to such an unheroic, non-Kitchian role.

VI. LESSONS

The story behind the fracking revolution offers a number of lessons. First, there is the point that the necessary precursors for this revolution did not develop overnight. As two commentators have suggested, "the history of unconventional gas technology development demonstrates how many threads of effort came together from sometimes unexpected sources over a period of decades before resulting in identifiable successes."[323] Key technologies such as hydraulic fracturing and directional drilling were decades in the making, with patent and other records suggesting that both major producers and service companies played important roles in developing foundational technologies. Despite having such technologies to build on, even the final breakthroughs by Mitchell required years of effort and risk on top of what had already been done before. This aspect of the story of fracking highlights that both patience and, perhaps more to the institutional-design point, innovation-reward mechanisms possessing substantial reliability over time can be crucial to fostering game-changing innovations. Complementary assets in the form of land and mineral leases can provide would-be innovators like Mitchell with a reliable prospect of substantial reward that entices them to take on what others might think a lost cause.

A second point relates to the value of diversity, diversification, and decentralization. The government's investment in unconventional natural gas—a field largely neglected by major producers—helped diversify the United States' "energy bets": if, in the late 1970s and early 1980s, both the government and private producers had uniformly focused on still available conventional energy sources that appeared to be better bets for near-term fossil-fuel production and profit, the United States might not have stumbled on the "winning hand" of shale gas production until much later than it did.

Diversity of the forms of private players who were in position to aid in the development of this winning hand seems also to have been crucial. The United States' possession of a throng of experienced independent producers and service companies helped avoid a situation in which the major

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[322] *See* Kitch, *supra* note 30, at 271-75 (comparing aspects of the United States' "mineral claim system" and the patent system).

[323] Executive Summary, *in* BURWEN & FLEGAL, *supra* note 53, at 2.

producers' neglect would have required the government to try to develop from scratch the institutional means to pursue development in this area. Moreover, the existence of a decentralized, competitive throng of independent producers meant there were ample entities ready and eager—not slowed by lumbering internal bureaucracies, and spurred by competition and fear of lost opportunity—to implement the Mitchell synthesis on a grand scale once shale gas production was commercially viable.

More generally, the separate roles in this story played by different forms of private players—major producers, service companies, and independents such as Mitchell—indicate the potential value of an economic and regulatory ecosystem that can support a diverse range of business models. As biological diversity can make species more robust and adaptable to new circumstance, diversity in enterprise forms can render an economic system hardier and nimbler in exploiting new opportunities. With major producers and service companies playing key roles in making the fracking revolution possible and with independents taking the key risks that made the revolution a reality, the story of the fracking revolution appears to illustrate the potentially epoch-making benefits of business-model diversity.

A third point is that, despite the private sector's undeniably crucial role in bringing about the fracking revolution, government also played a crucial part. Either directly or through beneficiaries such as the Gas Research Institute, government played vital parts in providing complementary or supplementary funding, helping coordinate private efforts, encouraging information exchange, and facilitating innovation-favoring aspects of private markets. Although major producers and major service companies contributed much to foundational innovation over the course of decades,[324] government-funded R&D seems likely to have been necessary to put a spur to unconventional gas development in the late 1970s. Largely neglected by major producers, this subfield was dominated by independent producers who commonly lacked generous research and development budgets.[325] Thus, the early, long-term, and relatively reliable support that came through direct federal funding, through often cooperative federal projects, and through the federally sponsored Gas Research Institute helped fill gaps that the private markets might have otherwise left open. The federal government seems reasonably credited with having added value by helping to seed the subfield of unconventional gas development with critical early information, significant innovations, and a culture of information exchange.

A fourth point, already suggested but worth elaboration, is that the factors that led to this technological revolution were multifarious to an

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[324] *See supra* text accompanying notes __.
[325] MIT Study, *supra* note __, at app.8A:1.

extent that even the above points do not adequately capture. Although the risks taken and ingenuity shown by individuals should not be belittled, the boom in shale gas extraction reflects an intricate combination of external support in the form of access to markets and infrastructure, cross-sector innovations and sub-innovations at and beyond the wellhead, and governmental support through research, tax benefits, and regulatory exemptions. The roles played by these factors provide valuable lessons for other segments of the energy industry, which share many of the characteristics of oil and gas.

As discussed in Part I, the energy industry is highly resource and location-dependent, which makes external support in the form of infrastructure and access to markets crucial. Oil, gas, heat (for geothermal), sunlight, and wind must be captured wherever they happen to be abundant, and transport technology must be installed at these locations.

The need for infrastructure raises potential public goods or monopoly problems that, generally speaking, the availability of patent rights cannot solve.[326] At least from the standpoint of minimizing risk, there can be a strong "second-mover advantage" that, in principle, could leave everyone "waiting for Godot." Fuel extractors and generators will wait for a guarantee that transportation will be built, and transportation companies will wait for a commitment from extractors and generators to use their transportation. The first movers in each sector—those who first drill, or build transportation infrastructure—take on the highest risk. Although first movers might be rewarded for shouldering this risk, they could lose in a big way; the oil and gas play might not be productive, or wind generators might not be built at the rates that the first movers had anticipated. If this is the case, the entities who first build transportation infrastructure will have few customers. If the area is productive, on the other hand, the first mover who has built the pipelines or transmission lines is required by federal law to offer open access to the transportation. This solves monopoly problems but raises concerns about free riding by "second movers." If cost allocation for the infrastructure is not done properly, the open-access users of the transportation (and retail customers) might benefit at the expense of others who had to pay the bulk of the costs for infrastructure development.

The experience of the fracking revolution suggests that public policy is crucial in solving these infrastructural challenges. The grant of federal certificates of need and eminent domain authority incentivized the construction of interstate natural gas pipelines, while price regulation of gas

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[326] *Cf.* BRETT M. FRISCHMANN, INFRASTRUCTURE: THE SOCIAL VALUE OF SHARED RESOURCES 14-15 (2012) (discussing likely "underprovision" of infrastructure and "standard solutions").

transportation service and open-access requirements addressed behavior that would have limited pipeline's usefulness to producers. In the electric generation industry, the federal government attempted a similar federalization of transmission-line siting,[327] but federal courts quickly rebuked this effort.[328] Regional organizations that provide coordinated planning for the upgrade and expansion of the transmission grid, however, have begun to encourage the construction of transmission lines needed for new generation—particularly for fast-growing wind farms.[329]

Whether a company is drilling for oil, gas, or heat (for geothermal energy), or installing solar or wind technologies to capture sunlight or wind, a combination of effective technology and strategic deployment of this technology is required. This leads to another lesson that emerges from the fracking case study and that seems likely to apply widely to development of new energy sources: innovation far beyond the technologies at the wellhead (or wind turbine) can be essential, and lines of sub-innovations within the industry can be equally vital. Often, one technological advance is not enough. The abundance of oil and gas in an underground formation can vary within several inches—energy operators often target a one foot-thick segment of a formation more than a mile underground.[330] Missing by a matter of inches could equate to losses of millions of dollars. Similarly, a small shadow regularly cast on an array of solar panels can, over time, powerfully influence the total kilowatts produced by those panels. In such situations, innovation in universal, readily transferable aspects of energy technology is just one piece of the puzzle: location-specific innovations that inform the effective implementation of technology are also crucial. These include, for example, the development of better testing to locate oil and gas resources underground (as DOE did for shale gas in West Virginia, Ohio, and Kentucky), and wind forecasting to predict wind speeds.

[327] Energy Policy Act of 2005, adding section 216 of the Federal Power Act.

[328] Piedmont Envtl. v .FERC (9th Cir. 2011) (rejecting FERC's argument that it can grant a federal permit for the construction of a transmission line when a state has denied a permit); Cal. Wilderness Coalition v. DOE (9th Cir. 2011) (holding that the Department of Energy, in designating National Interest Electric Transmission Corridors, in which FERC could grant permits for the construction of new transmission lines under certain conditions, inadequately consulted with states).

[329] *See* Illinois Commerce Commission v. FERC (7th Cir. 2013) (describing the Midwestern Independent System Operator's (MISO's) identification of areas with the most valuable wind resources and planning for the construction and financing (through rate recovery) of transmission lines from new wind farms to areas of electricity demand, and affirming the validity of MISO's cost allocation scheme for these lines).

[330] *See supra* note 76 and accompanying text.

Where private actors lack interest or means to pursue such innovations, the government might need to open its purse strings. In the oil and gas sector, confidential seismic testing conducted by industry consortia has supported resource location, but the Department of Energy also plays a key role conducting broader surveys and mapping out the oil and gas fields that are likely to become productive "plays"—areas with proven reserves for which commercial exploitation is economically viable. For renewables, the National Renewable Energy Laboratory conducts wind forecasting research that reduces the expense of determining the best locations for wind turbines and projecting future energy generation and, thus, future profits. This improved forecasting, combined with software technology innovations that continue to increase turbine efficiency by up to one percent annually, has pushed the wind industry forward in a way analogous to the role of state-sponsored geological surveys in supporting efforts at fossil-fuel extraction.

More generally, the diverse mix of technological developments needed to generate the shale gas boom suggests two things about the policy levers best suited to promote such innovation: (1) employment of a diverse set of levers whose use is adapted over time might best support the distinct and time-variant forms of advances that need to be made, and (2) the diverse array of sub-technologies involved and thus diverse forms of expertise and resources required might make particularly suspect any notion that an individual private actor can effectively coordinate all the relevant innovative effort. In short, in such a diverse and uncertain policy and technological environment, a broad Kitchian "prospect patent," one meant to facilitate centralized private coordination,[331] might be more problematic than helpful. Indeed, lightly coordinated development through DOE intervention and GRI leadership seem to have combined with largely patent-free exploration of technological possibilities to ultimately produce Mitchell's "fracking synthesis" and its stunningly rapid implementation by a swarm of independents throughout the United States. Particularly in light of Robert Merges and Richard Nelson's accounts of broad, early-stage patents that have appeared to slow innovation,[332] the story of the United States' fracking revolution stands as an example of a situation in which restraints on patenting might have in fact facilitated technology's rapid development, dissemination, and refinement.

On the other hand, the significant presence of patents on innovations that ultimately formed part of the "Mitchell synthesis" suggests that patents

[331] *See supra* text accompanying notes 315-316.
[332] *See* Merges & Nelson, *supra* note 318, at 877 ("We can present empirical evidence that the granting of broad patents in many cases has stifled technical advance and that where technical advance has been rapid there almost always has been considerable rivalry.").

might not have played an entirely negligible role. Consistent with a more modest view of the patent system than that commonly championed today, patents might have been most helpful not in stimulating the most prominent or "heroic" breakthroughs leading to the fracking revolution, but instead in helping to stimulate over a span of decades a continual trickle of "smaller"—in an approximation of Merges and Nelson's terms, narrowly claimed or enforced[333]—component innovations that ultimately provided the fodder for Mitchell's synthesis.

In addition to highlighting this potentially important but relatively modest role for patents, the story behind the fracking revolution generally suggests the importance of a variety of government mechanisms for supporting innovation as well as the importance of progressive adaptation of those mechanisms and the regulatory environment as circumstances change. Under appropriate circumstances, the government can play a crucial early role by seeding a field with basic information, enabling technology, and infrastructure that provide private actors with grounds for interest. Once private actors are active in the area, the government might focus more on cooperative efforts and coordination. Finally, once commercialization has taken off, government should consider recalibrating regulation to check potential negative side effects and to limit potentially wasteful regulatory subsidization of a no longer infant industry.

In short, in developing innovation policy, governments can build on a substantial number of lessons from fracking's successes and frustrations. Such lessons might be particularly applicable to the development of renewable energies.[334] More generally, the story of the fracking revolution suggests that an evolving portfolio of policy levers, responsive to developing circumstance and context, might be the best way to foster and sustain game-changing innovations that radically ratchet upward the possibility frontiers for nations and even the world as a whole.

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[333] *See id.* at 911 (suggesting that courts should "review patent scope … with an eye toward preventing the kind of blockage we have described").

[334] The National Renewable Energy Laboratory collaborates with private renewable energy entities on technology research, and the federal government's production tax credit has been a substantial driver of wind growth. The government also has relaxed certain regulatory standards for renewables, although not nearly to the extent of fossil fuel exemptions. The Department of the Interior, for example, has prioritized certain renewable energy projects on federal lands and has entered in memoranda of understandings with state agencies to try to streamline the environmental review process. For the most part, though, renewable energy projects encounter numerous regulatory hurdles that appear to substantially encumber progress. Jeffrey Thaler, Fiddling While the World Floods and Burns; Hannah Wiseman, Expanding Regional Renewable Energy Development.

CONCLUSION

The story of the twenty-first century's unprecedented boom in unconventional oil and gas development is far more complex than is often acknowledged. It involved a wide array of actors beyond George Mitchell, numerous technologies and innovations not directly relating to hydraulic fracturing, a moderate use of patents combined with the sharing of important information, and a long history of government research support, tax benefits, and regulatory and tax exemptions. It would be difficult, and perhaps impossible, to empirically identify which factor most influenced the burst of innovation seen in the last few decades. But although patents might have played an important role in protecting certain technological advances and thus incentivizing growth, they were far from the most prominent driver. Companies that developed key aspects of directional drilling and hydraulic fracturing patented many associated products or processes. But a lack of patenting of critical aspects of the Mitchell synthesis of slickwater fracturing and directional drilling appears to have contributed to an environment in which a large number of small, independent producers adopted the new techniques and multiplied their implementation with stunning rapidity.

Moreover, innovation within drilling and fracturing explains only part of the fracturing story. Substantial spurs to innovation came from a number of other technological improvements that emerged—sometimes fortuitously—alongside developments in drilling and fracturing. Improvements in computing in the mid-1980s greatly improved industry's 3D seismic imaging of underground oil and gas resources, and earlier on, stronger materials and welding techniques helped motivate the construction of interstate pipelines needed to carry gas to distant markets.

Government policies, too, appear to have played a key role in the shale gas boom. Direct federal research support for early hydraulic fracturing and seismic imaging to identify the characteristics of fractures targeted high-risk, costly development that many industry actors likely could not or would not have undertaken independently. Regulatory and tax exemptions, as well as tax credits, also reduced the cost of development. Although these cost savings might commonly have been relatively small compared to the overall cost of a project, they likely spurred at least some development at the margins by mitigating the concerns of cost-sensitive actors.

Finally, infrastructural development enabled by favorable policies combined with high natural gas prices to help launch nationwide adoption of the new techniques for recovering unconventional natural gas. Perhaps most notably, interstate natural gas pipelines with access to federal eminent domain authority, were required to provide access to customers on a first come, first-served nondiscriminatory basis—a boon to producers looking for assurance that they could reach consumers willing to pay higher prices.

All of these factors, although difficult to quantify in terms of their role in driving the shale gas boom, seem to have been key components in the technological revolution that has swept unconventional natural gas. This convergence of facilitating factors can provide lessons for policymakers looking to stimulate further innovation in the energy sector or elsewhere. Like many industries, the energy industry is characterized by projects with large up-front capital costs, shared needs for infrastructure, and numerous technologies for production and delivery. Perhaps more distinctively, innovation in the energy sector also tends to require experimentation with a variety of processes in an effort to find processes or process variants that are properly attuned to local geographic conditions. Just as fracturing and drilling require different techniques depending on the characteristics of the underlying rock, renewable technologies are sensitive to factors such as the local availability of surface space and the local intensity of renewable energy sources. The experience with fracking suggests that, to most effectively develop such renewable technologies, policymakers might want to consider a complex layering of policy levers—government funding and R&D support, encouragement of properly modulated use of private appropriation mechanisms such as intellectual property or complementary assets, the fostering of innovation-quickening coordination and information sharing, infrastructural development, and regulatory and tax benefits that help increase the present-value calculus for uncertain projects and perhaps particularly give a boost to innovative efforts by small and undercapitalized enterprises.

A final implication of the fracking revolution's lesson about the value of diversity, diversification, and decentralization in innovation ecosystems is a comparative one. If the government is to try to facilitate socially beneficial innovation, it should be wary of casting its net too narrowly. This conclusion might be particularly true for the area of energy, where there can be a risk of overinvestment and, in that sense, "over-innovation" in one area, with the results including a diversion of effort from another area and a consequent stultification of innovation in that area that could have long-term impacts. As shown by the shale gas boom, energy technologies and their application can require decades of development and far-sighted investment in technology areas or forms of resources that are not presently viewed as significant. As these technologies are developing, so, too, must an infrastructural network that can take years to build and perfect. Hence, excessive focus on one energy area to the detriment of another could leave the other years, perhaps decades, behind where it could have been, and we could have difficulty catching up.

Application of this insight to present-day policy concerns with renewable-energy technologies is straightforward. Just as fracking technologies required much site-specific, trial-and-error experimentation, wind and solar technologies require experimentation and adaptation to different conditions. Just as decades of developments in pipeline networks and markets for natural gas paved the way for the shale gas boom, a wind and solar energy boom will require a new network of transmission lines from rural, windy and sunny areas to population centers. Just as the federal government was attuned to the desirability of investing in unconventional gas resources at a time when major producers were focusing elsewhere, policymakers might want to be wary of how the shale gas boom might displace technological innovation and infrastructural developments in alternative energy technologies. The fracking revolution's lessons of diversity, diversification, and decentralization suggest not only that governments should generally seek properly balanced deployment of an array of policy levers, but also that they should generally seek balanced investment in an array of innovation targets.

As in many fields, innovation in energy can involve a complex mixture of factors with cumulative and interactive effects. Technological innovations in numerous fields—from computing to chemicals to sophisticated drilling equipment—combined to enable the shale gas boom. Government involvement facilitated specific technological advances, information sharing, and the development of key market and transport infrastructure. Although the United States might wait decades before experiencing another energy boom comparable to the current one, policymakers can look immediately for opportunities to plant the seeds for new game-changing innovations. As seen in the background story for the fracking revolution, they have a host of levers they can deploy.