THE FRACKING REVOLUTION: SHALE GAS AS A CASE STUDY IN INNOVATION POLICY

John M. Golden[*]
Hannah J. Wiseman[**]

ABSTRACT

The early 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 various questions that scholars have begun to explore, including questions of risk governance, federalism, and export policy. Relatively neglected, however, have been questions of why the technological revolution behind the boom occurred and what this revolution teaches about innovation theory and policy. The boom in U.S. shale gas production reflected long-gestating infrastructure developments, a convergence of technological advances, government-sponsored research and development, the presence or absence of intellectual property rights, rights in tangible assets such as land and minerals, and tax and regulatory relief. Consequently, the story behind the boom reaches far beyond the risk-taking and persistence of George Mitchell, whose independent production company achieved pioneering success with hydraulic fracturing (fracking) in Texas' Barnett Shale. Indeed, the broader story demonstrates how a blend of distinct policy levers, reasonably adjusted over time, can combine to foster a diverse innovation ecosystem that provides a robust platform for game-changing innovation. As exemplified by this story, the centrality of other policy levers can mean that patents play only a modest role, even in spurring technological development by profit-driven private

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[*] Loomer Family Professor in Law, The University of Texas at Austin.
[**] Attorneys' Title Professor, Florida State University College of Law. The authors thank Ivan Cassuto and Nick Wenker for research assistance. For comments, they thank Michael Abramowicz, David Adelman, Mark Ascher, Ian Ayres, Yochai Benkler, Mario Biagioli, Lynn Blais, Paul Bommer, Oren Bracha, Jens Dammann, Rebecca Eisenberg, Kinnan Golemon, Calvin Johnson, Jennifer Laurin, Jake Linford, Tom McGarity, Jim Morriss, Susan Morse, Sean O'Connor, Lucas Osborn, Bob Peroni, Richard Pierce, John Robertson, David Spence, James Spindler, Dan Steward, Melinda Taylor, Abe Wickelgren, Sean Williams, the editors of the *Emory Law Journal*, participants in the 2014 Works-in-Progress Intellectual Property Conference, the Yale Information Society Project's 2014 "Innovation Law Beyond IP" conference, a faculty colloquium at the University of Texas School of Law, and students in a Science and Innovation Policy seminar at the University of Texas at Austin.

players. Other lessons drawn from this case study include "negative lessons" about the possibility and even likelihood of downsides of a technological boom or the policies used to promote it—for example, environmental damage that more careful regulation of a developing technology such as fracking might have avoided. Anticipatory and continuing attention to such potential downsides can help prevent innovation-promoting policies from becoming "sticky" in a way that undercuts innovation's promise and popular appeal. Such lessons can helpfully inform efforts either to extend the United States' "fracking revolution" abroad or to develop other potentially revolutionary technologies such as those associated with renewable energy.

INTRODUCTION

Innovations in hydraulic fracturing and horizontal drilling (often collectively referred to as "fracking")[1] have produced a technological revolution in natural gas and oil extraction. The United States, the world leader in these technologies' development and exploitation, has suddenly returned to the role of energy-producing superpower.[2] Cheaper and more stably priced natural gas, commonly derived from underground shale formations, has promised to provide a long-lasting boost to a flagging U.S. economy,[3] even aiding in a revival of U.S.-based manufacturing.[4] Both positive and negative spillover effects associated with the boom in use of new extraction technologies—spillovers that range from the economic to the environmental or political[5]—promise to reach not only across the United States' continental

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1 There is debate over whether the abbreviated form of "hydraulic fracturing" should be "fracing" or "fraccing," rather than "fracking," with the latter form often being associated with more negative views of hydraulic fracturing as a social practice. RUSSELL GOLD, THE BOOM: HOW FRACKING IGNITED THE AMERICAN ENERGY REVOLUTION AND CHANGED THE WORLD 297 (2014). In using "fracking," we do not mean to take sides in debates over hydraulic fracturing's overall social benefits but instead follow what we believe to be the more dominant popular spelling as well as a spelling that seems to best signal how the term is pronounced. *See id.* at 297 n.* (explaining that the book employs "the spelling *frack* and *fracking*" because "they are the preferred spelling of the *Wall Street Journal* and other major newspapers" and because "the spelling *fraced* simply doesn't convey the clipped cadence of the word as it is pronounced by opponents and engineers"); *see also* GREGORY ZUCKERMAN, THE FRACKERS: THE OUTRAGEOUS INSIDE STORY OF THE NEW BILLIONAIRE WILDCATTERS 27 (2013) (explaining that industry initially called the technique "hydraulic fracturing" or "fraccing" and that "from the beginning industry members detested the word" fracking, and accused environmental groups of coining the term to imply negative impacts of the practice, but noting that the term originated in *Battlestar Galactica*).

2 *See U.S. Expected to Be Largest Producer of Petroleum and Natural Gas Hydrocarbons in 2013*, U.S. ENERGY INFO. ADMIN. (Oct. 4, 2013), http://www.eia.gov/todayinenergy/detail.cfm?id=13251.

3 *See* U.S. ENERGY INFO. ADMIN., ANNUAL ENERGY OUTLOOK 2014 EARLY RELEASE OVERVIEW 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.").

4 ALAN KRUPNICK, ZHONGMIN WANG & YUSHUANG WANG, RES. 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"); AM. CHEMISTRY COUNCIL, SHALE GAS, COMPETITIVENESS, AND NEW US CHEMICAL INDUSTRY INVESTMENT: AN ANALYSIS BASED ON ANNOUNCED PROJECTS 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 an estimated $2.2 billion in added value in 2012).

5 For discussions of these effects, see, *inter alia*, the following sources: Endangered and Threatened Wildlife and Plants, Endangered Species Status for Diamond Darter, 78 Fed. Reg. 45,074 (July 26, 2013)

breadth but around the globe.[6]

The technological revolution that preceded this U.S.-centered oil and gas boom 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 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, focusing on the development of shale gas extraction in particular. The Article primarily concentrates on developments leading to the revolution, including decades of work that preceded late-twentieth century breakthroughs. But the Article also gives some attention to the post-breakthrough diffusion of new extraction technologies and difficulties encountered as use of those technologies has become widespread.

(codified at 50 C.F.R. § 17.11 (2014)) (describing a species in the Marcellus Shale area that has become endangered in a final rule issued by the Department of the Interior's Fish and Wildlife Service); TIMOTHY W. KELSEY ET AL., MARCELLUS SHALE EDUC. & TRAINING CTR., ECONOMIC IMPACTS OF MARCELLUS SHALE IN PENNSYLVANIA: EMPLOYMENT AND INCOME IN 2009, at 5 (2011), http://www.shaletec.org/docs/EconomicImpactFINALAugust28.pdf (exploring positive economic benefits); KENNETH B. MEDLOCK III, AMY MYERS JAFFE & PETER R. HARTLEY, JAMES A. BAKER III INST. FOR PUB. POLICY, RICE UNIV., SHALE GAS AND U.S. NATIONAL SECURITY 13 (2011), http://bakerinstitute.org/media/files/Research/ccecf6b6/EF-pub-DOEShaleGas-07192011.pdf (describing many positive economic and security-based impacts); WILLISTON ECON. DEV., WILLISTON IMPACT STATEMENT 2014, at 1, 28 (2014), http://www.willistondevelopment.com/usrimages/Williston_Impact_Statement.pdf (describing local infrastructural and service-based impacts as well as tax revenues); Cliff Frohlich et al., *The Dallas–Fort Worth Earthquake Sequence: October 2008 Through May 2009*, 101 BULL. SEISMOLOGICAL SOC'Y AM. 327 (2011) (describing small earthquakes possibly induced by the disposal of liquid oil and gas wastes from the Barnett Shale); Michelle L. Hladik, Michael J. Focazio & Mark Engle, *Discharges of Produced Waters from Oil and Gas Extraction via Wastewater Treatment Plants Are Sources of Disinfection By-Products to Receiving Streams*, 466–467 SCI. TOTAL ENV'T 1085, 1092 (2014); Brian G. Rahm & Susan J. Riha, *Toward Strategic Management of Shale Gas Development: Regional, Collective Impacts on Water Resources*, 17 ENVTL. SCI. & POL'Y 12, 15 (2012) (describing water quality and quantity impacts); Hannah J. Wiseman, *Risk and Response in Fracturing Policy*, 84 U. COLO. L. REV. 729, 733–34 (2013) (describing many of the impacts based on state enforcement of oil and gas regulations at unconventional well sites).

6 *See generally* GOLD, *supra* note 1, at 5 (noting that, from the U.S. perspective, hydraulic fracturing "is providing an abundance of domestic energy, helping to drive a rebirth of manufacturing, and easing dependence on overseas energy peddlers"); Diana Davids Hinton, *The Seventeen-Year Overnight Wonder: George Mitchell and Unlocking the Barnett Shale*, 99 J. AM. HIST. 229, 229 (2012) ("[T]he opening of massive natural gas production in north Texas from a geological formation called the Barnett Shale has begun a new era in world energy.").

Studying innovation through a case study of the fracking revolution is apt in light of current levels of understanding. Limits on our knowledge of the mechanics of innovation often renders generalized theorizing and narrow econometric studies of relatively little use for drawing practical, policy-oriented conclusions. In this context, case studies of specific innovation trajectories can inform the intuitions that necessarily guide much present policymaking, and case studies can support and guide later theoretical and econometric efforts. Such focused observational studies have substantial limits. But we suspect that the physicist Richard Feynman had reason for listing observation first in describing "[o]bservation, reason, and experiment [as] mak[ing] up what we call the scientific method."[7] 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 advance understandings of innovation and innovation policy.[8]

Why study fracking as a foundation for more nuanced innovation theory? Pharmaceutical, biotechnology, communications, and computer-related technologies have commonly provided the basis for modern debates about how innovation works.[9] 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[10] and, second, even newer,

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

8 *Cf. 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"); GERALD HOLTON & STEPHEN G. BRUSH, INTRODUCTION TO CONCEPTS AND THEORIES IN PHYSICAL SCIENCE 38 (2d ed. 1973) (noting that Tycho Brahe "spen[t] nearly a lifetime in patient recording of planetary motion with unheard-of precision").

9 *See* John M. Golden, *Principles for Patent Remedies*, 88 TEX. L. REV. 505, 507 & nn.7–8 (2010) (describing conflicts over patent legislation that featured a coalition including "information technology, semiconductor, computer, and financial-services companies" on one side and a coalition, including "pharmaceutical, biotechnology, and chemical companies" on the other).

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

interconnected technologies for extracting coal and harnessing steam.[11] The modern Information Revolution has relied on later advances in the production and harnessing of electrical energy.[12]

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.[13] Indeed, 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 adapted with awesome rapidity to shale and other formations around the United States.[14]

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[11] *Id.* at 85 (observing that "[t]he 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").

[12] *Cf.* ALFRED C. CHANDLER, JR., INVENTING THE ELECTRONIC CENTURY: THE EPIC STORY OF THE CONSUMER ELECTRONICS AND COMPUTER INDUSTRIES, at xiv–xvii (rev. ed. 2005) (comparing the Information Revolution and the Industrial Revolution); Warren D. Devine, Jr., *From Shafts to Wires: Historical Perspectives on Electrification*, 43 J. ECON. HIST. 347, 371 (1983) (examining the historical "shift from steam power to electric power").

[13] *See* DANIEL YERGIN, THE QUEST: ENERGY, SECURITY, AND THE REMAKING OF THE MODERN WORLD 325 (2011) ("[M]itchell'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, at 5, 5–6, *available at* http://www.economist.com/node/21558459 (explaining that "the 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, *Origins: The Story of a Professor, a Gas Driller and Wall Street*, PITT. POST-GAZETTE, Mar. 20, 2011, at A-1, *available at* http://www.post-gazette.com/business/businessnews/2011/03/20/The-Marcellus-Boom-Origins-the-story-of-a-professor-a-gas-driller-and-Wall-Street/stories/201103200259 ("[I]n the early 1980s, Texas oilman George P. Mitchell pursued a fringe strategy—exploring the Barnett Shale."); *see also* ZUCKERMAN, *supra* note 1, at 5 (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, RES. FOR THE FUTURE, A RETROSPECTIVE REVIEW OF SHALE GAS DEVELOPMENT IN THE UNITED STATES: WHAT LED TO THE BOOM? 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 that "it was the private entrepreneurship from Mitchell Energy & Development . . . that played the primary role in developing the Barnett play in Texas"); ZUCKERMAN, *supra* note 1 (providing a richer account by describing efforts by Mitchell, leading individuals at Chesapeake Energy, and others in inducing the technological revolution).

[14] *See infra* text accompanying notes 84–91; *see also* MICHAEL RATNER & MARY TIEMANN, CONG. RESEARCH SERV., R43148, AN OVERVIEW OF UNCONVENTIONAL OIL AND NATURAL GAS: RESOURCES AND

But even a Mitchell-centric view of fracking's development acknowledges that there were other factors that contributed critically to the technological revolution behind commercially viable shale gas extraction and the associated boom in oil and gas production more generally. A great number of these related to physical, legal, and economic infrastructure including pipelines, natural gas markets, and property systems for land and mineral rights, which provided a foundation upon which unconventional natural gas pioneers could successfully operate.[15] Further vital preconditions for Mitchell's successful "fracking synthesis" included multiple lines of innovation—for example, in hydraulic fracturing, directional drilling, and seismic imaging to identify oil and gas deposits—that sometimes reached decades into the past.[16]

Significantly, private forces for innovation benefited substantially from public aid. In the 1970s and 1980s, the U.S. Bureau of Mines (later part of the Energy Research and Development Administration)[17] and Department of Energy (DOE) "spent hundreds of millions"[18] on research and development that helped both point and pave the way for Mitchell's ultimate success.[19] Moreover, public support extended far beyond early R&D. Fracking and associated technologies have long benefited from public–private research

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FEDERAL ACTIONS 3 (2014), http://fas.org/sgp/crs/misc/R43148.pdf ("The application of advances in directional drilling and hydraulic fracturing were first applied to shale gas formations, particularly as natural gas prices increased in the mid-2000s.").

15 *See* WANG & KRUPNICK, *supra* note 13, at 4 (discussing the importance of property systems in land and mineral rights); *America's Bounty*, *supra* note 13, at 5 (discussing factors behind the fracking revolution such as "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 liberalisation of access to existing pipelines by third parties").

16 *See infra* notes 62–80 and accompanying text.

17 For a discussion of consolidations in the 1970s, after which the Department of Energy (DOE) oversaw all energy R&D, see WANG & KRUPNICK, *supra* note 13, at 7–8.

18 Alex Trembath, Letter to the Editor, *A Joint Effort*, ECONOMIST, Aug. 4, 2012, at 14, *available at* http://www.economist.com/node/21559890.

19 MICHAEL SHELLENBERGER ET AL., BREAKTHROUGH INST., WHERE THE SHALE GAS REVOLUTION CAME FROM 6 (2012), http://thebreakthrough.org/images/main_image/Where_the_Shale_Gas_Revolution_Came_From2.pdf (discussing how the Bureau of Mines' Morgantown Energy Research Center "initiated the Eastern Gas Shales Project, which established a series of partnerships with universities and private companies" to demonstrate gas recovery from "unconventional resource bases that stood out of reach from contemporary drilling technologies, including coalbed methane deposits, "tight sands" natural gas, and shale gas"); *id.* at 3 (noting that Department of Energy's role in the first demonstrations of "massive hydraulic fracturing" and "directional drilling in shale"); *see also* WANG & KRUPNICK, *supra* note 13, 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").

partnerships[20] as well as both tax[21] and regulatory[22] relief.[23] Further, 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.[24]

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 "prospect theory" for relatively broad patent rights,[25] "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."[26] Far from holding fracking's further development back, such restraint in patenting might have helped enable the recent natural

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20 SHELLENBERGER ET AL., *supra* note 19, at 9 ("In 1991, Mitchell partnered with DOE and GRI [the federally funded Gas Research Institute] to develop tools that would effectively fragment formations in the Barnett Shale . . . .").

21 Trembath, *supra* note 18, at 14 (noting that the U.S. government offered a "$10 billion production tax credit for unconventional gas between 1980 and 2002").

22 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."); *cf.* Michael Burger, Response, *Fracking and Federalism Choice*, 161 U. PA. L. REV. ONLINE 150, 157 (2013) ("[D]ue to a toxic blend of agency capture, flawed research, and shortsighted administrative decisions, the federal government's leadership in fracking regulation has been paralyzed.").

23 *Cf.* Daniel J. Hemel & Lisa Larrimore Ouellette, *Beyond the Patents–Prizes Debate*, 92 TEX. L. REV. 303, 311–12 (2013) (describing how prizes, grants, and tax relief, as well as intellectual property rights, can affect a would-be innovator's incentives).

24 Barbara Warner & Jennifer Shapiro, *Fractured, Fragmented Federalism: A Study in Fracking Regulatory Policy*, 43 PUBLIUS 474, 486 (2013) (noting that various states limit disclosure requirements for fracking chemicals "that companies deem proprietary"); Hannah Wiseman, *Trade Secrets, Disclosure, and Dissent in a Fracturing Energy Revolution*, 111 COLUM. L. REV. SIDEBAR 1, 4–8 (2011) (describing federal and state trade secret allowances). 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.*, 36 TEX. REG. 9307, 9312 (Dec. 30, 2011) (noting comments calling for greater disclosure of "proprietary chemicals"); Email from Mark Mackin to Tom Richmond, Mont. Bd. of Oil & Gas Conservation (June 5, 2011, 11:52 AM), *available at* http://bogc.dnrc.mt.gov/PDF/CombinedComments.pdf (page sixteen of the file) (calling for greater disclosure of chemicals used in hydraulic fracturing).

25 Edmund W. Kitch, *The Nature and Function of the Patent System*, 20 J.L. & ECON. 265, 266 (1977) (arguing that the patent system enables a patent owner to coordinate exploitation of a "prospect"—"a particular opportunity to develop a known technological possibility"—in a way that increases social efficiency); *see also id.* 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").

26 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, 291 (2013).

gas "gold rush," "with companies racing to capitalize on innovative, yet unpatented techniques in other geographies."[27] 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.

Generally speaking, the translation of lessons from one technological and social context to another can be perilous. Nonetheless, the story behind the fracking revolution provides lessons both for innovation theory and also, at least at a strategic level, for specific problems of technological development in the present day. In particular, the story provides lessons that can productively inform efforts to replicate the United States' shale gas boom abroad and efforts to revolutionize wind and solar markets at home. These lessons include not only "positive lessons" about how to promote innovation but also "negative lessons" about how to avoid or mitigate downsides of innovation that could undercut innovation's promise and popular appeal. As with many technological booms, environmental concerns[28] and social dislocations[29] have accompanied the shale gas boom, and their emergence affords instruction in how policymakers might act anticipatorily or reactively to maximize technology's potential.

This Article's exploration of the story of the fracking revolution proceeds as follows. Part I introduces the wellhead technologies that converged to generate the "Mitchell synthesis" of techniques of horizontal drilling and hydraulic fracturing. Part II explores factors beyond the wellhead—in particular, the development of open-access pipelines and national markets in natural gas. Part III describes the role of federal and state governments in advancing hydraulic fracturing and horizontal drilling through such policy mechanisms as research partnerships and regulatory and tax relief. Part IV discusses how private property rights in land and minerals, patents, secrecy, and information exchange contributed to the technological developments behind the shale gas boom. Part V explores lessons, positive and negative, from this case study in technological innovation and potential application of

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27 *Id.* at 291–92.

28 *See infra* notes 262–66 and accompanying text.

29 *See infra* notes 268–70 and accompanying text.

these lessons to oil and gas development abroad and renewable-energy development in general. A concluding section follows.

I. THE SHALE GAS BOOM AND 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 Article focuses on the most revolutionary field of these technologies' recent use—the extraction of natural gas from underground shale formations, which consist of "hard, concretelike shale rock"[30] formed by sediment and organic matter that accumulated in formerly marine environments.[31] The Article focuses on shale gas extraction because development of unconventional reserves of shale gas is commonly recognized to be at the heart of the now more general oil and gas boom[32] and because, among affected fossil fuels, newly exploitable natural gas reserves seem to have the greatest potential for disruption of energy economies historically tied more tightly to oil and coal.[33] This Part discusses the United States' shale gas boom and the intricate combination of technological developments that lies behind it.

A. Boom in U.S. Production 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

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30 YERGIN, *supra* note 13, at 326.

31 Q.R. PASSEY ET AL., SOC'Y OF PETROL. ENG'RS, SPE 131350, FROM OIL-PRONE SOURCE ROCK TO GAS-PRODUCING SHALE RESERVOIR—GEOLOGIC AND PETROPHYSICAL CHARACTERIZATION OF UNCONVENTIONAL SHALE-GAS RESERVOIRS 10 (2010) (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").

32 *Shale of the Century*, ECONOMIST, June 2, 2012, at 77, *available at* http://www.economist.com/node/21556242 ("As a proportion of America's overall gas production shale gas has increased from 4% in 2005 to 24% today.").

33 *See, e.g.*, *Monthly Coal- and Natural Gas-Fired Generation Equal for First Time in April 2012*, U.S. ENERGY INFO. ADMIN. (July 6, 2012), http://www.eia.gov/todayinenergy/detail.cfm?id=6990 (noting that "for the first time since EIA began collecting the data, generation from natural gas-fired plants is virtually equal to generation from coal-fired plants, with each fuel providing 32% of total generation," in April 2012 in part because "natural gas prices as delivered to power plants were at a ten-year low"); *Natural Gas Generation Lower than Last Year Because of Differences in Relative Fuel Prices*, U.S. ENERGY INFO. ADMIN. (Sept. 25, 2013), http://www.eia.gov/todayinenergy/detail.cfm?id=13111 ("The increasing gas use for power is a structural change that is occurring across a wide range of temperatures and seasons. Several factors underpin this trend, including moderate natural gas prices, increased shale gas production, and additions of natural gas generating capacity.").

very first years of the twenty-first century. Already in 2001, after surveying a history of relatively incremental progress but before recognizing the imminence of the impending boom, the National Research Council declared past public support for shale gas a substantial success.[34] The Council reported that in the mid-1970s the United States extracted about 70 billion cubic feet (Bcf) of natural gas per year from shale formations.[35] By 1998, that amount had risen by over a factor of five to 380 Bcf per year.[36] 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.[37] 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.[38] A much higher benefit-to-cost ratio would have resulted from taking into account "over $8 billion in consumer savings due to lower gas prices."[39] 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.[40]

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,"[41] the United States

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34 NAT'L RESEARCH COUNCIL, ENERGY RESEARCH AT DOE: WAS IT WORTH IT? ENERGY EFFICIENCY AND FOSSIL ENERGY RESEARCH 1978 TO 2000, at 201 (2001), http://www.nap.edu/catalog/10165.html ("[I]ncentives through tax credits, combined with optimum deployment of advanced technology, served to revive a domestic gas province in decline.").

35 *Id.*

36 *Id.*

37 *Id.*

38 *Id.*

39 *Id.*

40 In 2002, another set of commentators reacting to unconventional natural gas production levels of 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*, J. ENERGY & ENVTL. RES., Feb. 2002, at 75, 81 (citing 1999 production level of 4,500 Bcf, 370 Bcf of which resulted from gas shale production). 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.

41 NAT'L RESEARCH COUNCIL, *supra* note 34, at 201.

extracted nearly 2 Tcf of shale gas.[42] 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.[43] If the growth in shale gas production were exponential, production would have taken another couple of decades to rise by another factor of five.[44] 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.[45] 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,[46] more than five times the production level in 2007 and about ten times the amount that the National Research Council had projected for 2020.[47] From 2000 to 2012, shale gas had gone from supplying only about 1% of the United States' natural gas to supplying well over one-fourth.[48] As Daniel Yergin put it, "[p]erennial shortage gave way to substantial surplus."[49] The United States now looks forward to becoming a net exporter of natural gas.[50]

The world is still absorbing the significance of this natural gas boom, one that has helped turn the United States into an unexpected, technology-driven "petrostate" of a type never seen before.[51] The "shale gale"[52] of the past decade has generated a vast range of straightforward economic benefits, including improved GDP and balance-of-payments numbers, increased employment and

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42 *U.S. Natural Gas Withdrawals from Shale Gas (Million Cubic Feet)*, U.S. ENERGY INFO. ADMIN. (Aug. 29, 2014), http://www.eia.gov/dnav/ng/hist/ngm_epg0_fgs_nus_mmcfa.htm [hereinafter *U.S. Natural Gas Withdrawals*].

43 *See supra* text accompanying note 38.

44 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)).

45 *Compare supra* text accompanying note 36, *with supra* text accompanying note 42.

46 *U.S. Natural Gas Withdrawals*, *supra* note 42.

47 *See supra* text accompanying note 37.

48 YERGIN, *supra* note 13, at 329.

49 *Id.*

50 JASON BURWEN & JANE FLEGAL, AM. ENERGY INNOVATION COUNCIL, UNCONVENTIONAL GAS EXPLORATION & PRODUCTION 7 (2013) ("The US is now expected to become a net exporter of natural gas in the next decade.").

51 *The Petrostate of America*, ECONOMIST, Feb. 15, 2014, at 10, *available at* http://www.economist.com/news/leaders/21596521-energy-boom-good-america-and-world-it-would-be-nice-if-barack-obama-helped (noting that the United States' "'fracking' revolution . . . . owes less to geological luck than enterprise, ready finance and dazzling technology").

52 YERGIN, *supra* note 13, at 329 (internal quotation marks omitted).

tax revenues,[53] and by at least one estimate "on the order of $100 billion of gains to consumers each year."[54] Low natural gas prices have helped revitalize U.S. manufacturing, particularly in the natural-gas-dependent petrochemicals industry.[55] 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.[56] Finally, although records of incidents at shale gas sites, as well as broader scientific data, show a range of negative environmental effects that have been associated with natural gas extraction,[57] ample supplies of natural gas offer the possibility of significant environmental benefits—particularly if concerns with methane leakage from wells, gathering lines, and pipelines are addressed.[58] Natural gas is a much cleaner-burning fuel

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53 *See* Thomas W. Merrill & David M. Schizer, *The Shale Oil and Gas Revolution, Hydraulic Fracturing, and Water Contamination: A Regulatory Strategy*, 98 MINN. L. REV. 145, 157 (2013) (reporting on combined contributions of unconventional fossil fuel resources to U.S. economic figures).

54 BURWEN & FLEGAL, *supra* note 50, at 7.

55 *See* AM. 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 53, at 159.

56 *See* Merrill & Schizer, *supra* note 53, at 162–63 (suggesting that U.S. natural gas could reduce European dependence on Iran and Russia, as well as "enabl[ing] the U.S. to cut its defense budget"); *The Petrostate of America*, *supra* note 51, at 11 ("A world in which the leading petrostate is a liberal democracy has much to recommend it."). *But see* BakerInstitute, *Shell Distinguished Lecture Series—World Energy Outlook*, YOUTUBE (Feb. 20, 2014), https://www.youtube.com/watch?v=WcVNrWZ9rwU (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).

57 *See supra* note 5; *infra* notes 262–69 and accompanying text; *see also* GOVERNOR'S MARCELLUS SHALE ADVISORY COMMISSION REPORT 75 (2011), http://files.dep.state.pa.us/PublicParticipation/MarcellusShaleAdvisoryCommission/MarcellusShaleAdvisoryPortalFiles/MSAC_Final_Report.pdf (documenting certain "high-profile" well blowouts at fractured wells); E.T. SLONECKER ET AL., US GEOLOGICAL SURVEY, LANDSCAPE CONSEQUENCES OF NATURAL GAS EXTRACTION IN BRADFORD AND WASHINGTON COUNTIES, PENNSYLVANIA, 2004–2010, at 26 (2012), http://pubs.usgs.gov/of/2012/1154/of2012-1154.pdf (noting that both conventional and unconventional wells cause forest fragmentation, which can have negative effects on "interior species" that prefer undisturbed habitat); Mitchell J. Small et al., *Risks and Risk Governance in Unconventional Shale Gas Development*, 48 ENVTL. SCI. & TECH. 8289, 8290–91 (2014) (exploring the scientific literature and summarizing the risks); *cf.* Katie M. Keranen et al., *Potentially Induced Earthquakes in Oklahoma, USA: Links Between Wastewater Injection and the 2011 M_w 5.7 Earthquake Sequence*, 41 GEOLOGY 699, 701–02 (2013) (noting that injection of liquid wastes from oil and gas wells might have triggered a large earthquake in Oklahoma but not isolating this observation to wastes from unconventional wells).

58 For discussions of methane leakage at various points in the process of producing, transporting, and using natural gas, see, for example, David T. Allen et al., *Measurements of Methane Emissions at Natural Gas Production Sites in the United States*, 110 PNAS 17,768, 17,772 (2013) (estimating lower emissions from wellheads than the EPA has estimated, but noting uncertainty), and A.R. Brandt et al., *Methane Leaks from North American Natural Gas Systems*, 343 SCIENCE 733 (2014) (finding high methane emissions from natural gas used in transportation).

than coal and has already contributed to recent declines in the United States' greenhouse gas emissions.[59] In a post-Great Recession world highly concerned with promoting economic growth, there is hope that, with appropriate regulation of extraction and use, natural gas can act as a "bridge fuel," enabling relatively painless reductions in near-term greenhouse gas emissions while the world works toward greater reliance on nonfossil fuels.[60]

B. The 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. A horizontal well existed at least as early as 1929,[61] and judges, scholars, and industry experts have commonly traced hydraulic fracturing to increase fuel extraction back to the late 1940s.[62] But the combination and enhancement of these techniques by a host of improvements and ancillary technologies have yielded results that are qualitatively new.

Fundamentally, 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

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59 *See* U.S. ENERGY INFO. ADMIN., U.S. DEP'T OF ENERGY, NO. DOE/EIA-0560(98), NATURAL GAS 1998: ISSUES AND TRENDS 52–53, 53 fig.22 (1999), http://www.eia.gov/pub/oil_gas/natural_gas/analysis_publications/natural_gas_1998_issues_trends/pdf/it98.pdf (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 22, at 440–41 (citing these data and emphasizing the cleaner-burning qualities of gas).

60 J. Rothstein, *Hydrogen and Fossil Fuels*, 20 INT'L J. HYDROGEN ENERGY 283, 284 (1993); *see also* JOHN D. PODESTA & TIMOTHY E. WIRTH, CTR. FOR AM. PROGRESS, NATURAL GAS: A BRIDGE FUEL FOR THE 21ST CENTURY (2009), http://cdn.americanprogress.org/wp-content/uploads/issues/2009/08/pdf/naturalgasmemo.pdf; Merrill & Schizer, *supra* note 53, at 165–66; Hannah Wiseman, *Regulatory Adaptation in Fractured Appalachia*, 21 VILL. ENVTL. L.J. 229, 231–32 (2010).

61 BURWEN & FLEGAL, *supra* note 50, at 3.

62 Coastal Oil & Gas Corp. v. Garza Energy Trust, 268 S.W.3d 1, 7 (Tex. 2008) ("First used commercially in 1949, fracing is now essential to economic production of oil and gas and commonly used throughout Texas, the United States, and the world."); Carl T. Montgomery & Michael B. Smith, *Hydraulic Fracturing: History of an Enduring Technology*, J. PETROLEUM TECH., Dec. 2010, at 26, 26–27 ("The first experimental treatment to 'Hydrafrac' a well for stimulation was performed in . . . Kansas, in 1947 . . . ."); *Hydraulic Fracturing 101*, HALLIBURTON, http://www.halliburton.com/public/projects/pubsdata/Hydraulic_Fracturing/fracturing_101.html (last visited Mar. 5, 2015) (stating that Halliburton "first" used "the process in 1947 to stimulate flow of natural gas from the Hugoton field in Kansas").

pressure that the rock fractures.[63] In a natural-gas-bearing shale formation, the cracking of the hard but slightly porous rock helps expose surface area of the shale[64] and frees natural gas trapped within the shale to travel through the wellbore to the surface, where it is collected, processed, and transported, typically by pipeline.[65]

The oil and gas industry long sought to increase recovery of fossil fuels through predecessor techniques to hydraulic fracturing. Beginning in the 1860s, some operators used nitroglycerin to generate underground explosions in wells,[66] and by the 1930s, enterprising individuals injected acid into wells to open up fractures in surrounding formations.[67] Hydraulic fracturing emerged in 1947, when Floyd Farris of Stanolind Oil and Gas Corporation (later Amoco) performed an experimental "[h]ydrafrac" in Kansas, using 1,000 gallons of gasoline thickened with napalm followed by a gel injection to fracture a limestone formation.[68]

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.[69] Proppant particles are trapped in cracks generated by fracking and help "prop" them open—facilitating the continued flow of gas through the fractures.[70] For decades, operators have experimented with various combinations and concentrations of gels, proppants, and water (and sometimes foam)—often

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63 *See* BURWEN & FLEGAL, *supra* note 50, at 2 & fig.2; CHING H. YEW, MECHANICS OF HYDRAULIC FRACTURING 1 (1997) ("This fluid pressure creates a fracture extending into the rock medium which contains oil or gas.").

64 *See* P. KAUFMAN, G.S. PENNY & J. PAKTINAT, SOC'Y OF PETROL. ENG'RS, SPE 119900, CRITICAL EVALUATIONS OF ADDITIVES USED IN SHALE SLICKWATER FRACS, 1 (2008) (noting that horizontal wells are used to "create as much contact with the reservoir as possible").

65 *See* C. CLARK ET AL., ARGONNE NAT'L LAB., ANL/EVS/R-125, HYDRAULIC FRACTURING AND SHALE GAS PRODUCTION: TECHNOLOGY, IMPACTS, AND REGULATIONS 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").

66 Montgomery & Smith, *supra* note 62, at 26–27.

67 *Id.*

68 *Id.* (internal quotation marks omitted).

69 *Id.* at 28.

70 *See* BURWEN & FLEGAL, *supra* note 50, at 2; CAROLYN SETO, THE FUTURE OF NATURAL GAS SUPPLEMENTARY PAPER SP 2.3: ROLE OF TECHNOLOGY IN UNCONVENTIONAL GAS RESOURCES 11–12 (2011), http://mitei.mit.edu/system/files/Supplementary_Paper_SP_2_3_Unconventional_Technology.pdf; YEW, *supra* note 63, at 61.

varying the technique for different formations.[71] The nature of the fracking fluid and proppant is generally tailored to the particular geological formation being fracked.[72] For the types of shale gas formations of concern here, the fracking mixture tends to be at least about 98% to 99% water and sand, with the remainder comprising any of a number of substances.[73] These substances can include "friction reducing" agents such as polyacrylamides, biocides such as methanol to kill bacteria, "scale inhibitors" such as hydrochloric acid, 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 viscosity and the ability to carry and release proppant.[74] Proppants can also be varied in terms of grain size, shape, coating, or source.[75] 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."[76] Industry players have apparently been willing to look far and wide for materials that could help improve fracturing solutions or proppants: in the 1970s, energy companies "'borrowed' [chemical agents] from the plastic explosives industry."[77]

Such broad experimentation reflects the trial-and-error approach through which fracking has commonly developed—an approach that at least partly

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71 *See* Wiseman, *supra* note 5, at 744 n.60 (compiling and describing sources on historic fracturing fluids and treatments).

72 *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 (emphasis omitted)); KAUFMAN ET AL., *supra* note 64, at 1 ("[T]he selection of the fluid and additives [is] based upon the mineralogy.").

73 N.Y. DEPT. OF ENVTL. CONSERVATION, NATURAL GAS DEVELOPMENT ACTIVITIES & HIGH-VOLUME HYDRAULIC FRACTURING: SUPPLEMENTAL GENERIC ENVIRONMENTAL IMPACT STATEMENT 40–48 (rev. draft 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, *Fracking: An Industry Under Pressure*, 18 BERKELEY SCI. J., no.1, at 22, 25 (2013) ("Modern fracking fluid consists on average of 99.5% freshwater and sand and a mere 0.5% additives.").

74 GRAVES, *supra* note 72, at 100–01 (describing "slick water" fracking fluids); KAUFMAN ET AL., *supra* note 64 (describing the additives and their purposes); *supra* note 73.

75 GRAVES, *supra* note 72, at 102–03; *id.* at 106 ("The choice of sand type, its source, and its composition varies with each wellbore.").

76 Montgomery & Smith, *supra* note 62, at 28.

77 *Id.*

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.[78] Computer programs have been used to plan or simulate fracking operations since the mid-1960s,[79] but they have failed to remove all elements of personal skill and luck from the process.[80]

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.[81] To optimize gas recovery, another technology has frequently been necessary: effective "directional drilling" in which oil and gas companies drill a well vertically toward the formation that they are targeting, then progressively slant the drill bit, and ultimately drill laterally through the formation, sometimes for over a mile.[82] This horizontal drilling can address concerns with fracturing containment (limiting fractures to targeted areas of underground rock)[83] and, more intuitively for the inexpert, can allow more oil or gas to flow from the shale by exposing more surface area in the formation, both through the drilling itself and through the fractures that later emanate

78 *See, e.g.*, GRAVES, *supra* note 72, at 107 ("The modeling of the fluid dynamics of sand-infused liquids is an ongoing aspect of deep research in frac tech.").

79 Montgomery & Smith, *supra* note 62, at 31–32.

80 GRAVES, *supra* note 72, 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.").

81 PASSEY ET AL., *supra* note 31, at 2 (noting that "the vertical variability in organic richness can vary on relatively short vertical scales" that are "often much less than one meter").

82 HALLIBURTON, U.S. SHALE GAS: AN UNCONVENTIONAL RESOURCE. UNCONVENTIONAL CHALLENGES., 3 (2008) (noting that a "typical lateral" in the Barnett shale is "2,500 feet to 3,000 feet"); David Blackmon, *Horizontal Drilling: A Technological Marvel Ignored*, FORBES (Jan. 28, 2013, 3:31 PM), http://www.forbes.com/sites/davidblackmon/2013/01/28/horizontal-drilling-a-technological-marvel-ignored/ ("Horizontal Drilling now allows these [fracking] operators to drill and set pipe for a mile or more horizontally through this same rock formation.").

83 *See* Kent A. Bowker, *Development of the Barnett Shale Play, Fort Worth Basin*, SEARCH & DISCOVERY, Apr. 18, 2007, art. no. 10126, at 1, 12 http://www.searchanddiscovery.com/documents/2007/07023bowker/images/bowker.pdf (noting difficulty extending early successes in the Barnett Shale to areas where the shale was "not bound above and below by effective frac barriers," and observing that operators were "experimenting with various completion techniques (including four horizontal wells) . . . in an attempt to overcome the problem of fracing out of zone").

from the lateral wellbore.[84] Although a horizontal well might cost, say, twice as much as a traditional vertical well,[85] it can also be three times as productive, thereby substantially increasing the well's overall benefit-to-cost ratio.[86]

The existence of a basic 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.[87] Prior to the 1980s, available technologies were crude.[88] "Early directional drilling involved placing a steel wedge downhole (whipstock) that deflected the drill toward the desired target, but [this technique] lacked control and consumed time."[89] A great breakthrough came in the 1980s with the introduction of the "steerable downhole motor."[90] This decade also witnessed the first successful commercial horizontal drilling tests in the oil and gas sector, tests initiated in the early 1980s by a French operator that worked in southwestern France and offshore from Italy.[91] Later in the decade, U.S.

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84 *See* U.S. ENERGY INFO. ADMIN., U.S. DEP'T OF ENERGY, NO. DOE/EIA-TR-0565, DRILLING SIDEWAYS—A REVIEW OF HORIZONTAL WELL TECHNOLOGY AND ITS DOMESTIC APPLICATION 7 (1993); *see also* YERGIN, *supra* note 13, at 328 ("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.").

85 S.D. JOSHI, SOC'Y OF PETROL. ENG'RS, SPE 83621, COSTS/BENEFITS OF HORIZONTAL WELLS 2 (2003), *available at* http://www.joshitech.com/images/spe83621.pdf (estimating that U.S. newly drilled horizontal well costs to be "1.5 to 2.5 times more than a vertical well").

86 G. WATERS ET AL., SOC'Y OF PETROL. ENG'RS, SPE 103202, USE OF HORIZONTAL WELL IMAGE TOOLS TO OPTIMIZE BARNETT SHALE RESERVOIR EXPLOITATION 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").

87 John E. Fontenot, *Measurement While Drilling—A New Tool*, J. PETROLEUM TECH., Feb. 1986, at 128; *see also* Sara Pratt, *A Fresh Angle on Oil Drilling*, GEOTIMES (Mar. 2004), http://www.geotimes.org/mar04/feature_horizdrill.html.

88 Lynn Helms, *Horizontal Drilling*, DMR NEWSL. (N.D. Dept. of Mineral Res., Bismarck, N.D.), Jan. 2008, art. no. 2, at 2, *available at* https://www.dmr.nd.gov/ndgs/documents/newsletter/2008Winter/pdfs/Horizontal.pdf (asserting 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 larger size,] . . . for example, . . . for drilling holes in boiler-plates or other like heavy work" (internal quotation marks omitted)).

89 ANDREWS ET AL., *supra* note 72, at 19.

90 Pratt, *supra* note 87.

91 Helms, *supra* note 88, at 2; *see also* NAT'L RESEARCH COUNCIL, *supra* note 34, at 13 (describing the government role in this area as "absent or minimal," supporting that the U.S. government was not, for the most part, involved in horizontal drilling research or direct financial support); U.S. ENERGY INFO. ADMIN., *supra* note 84, at 7 (noting 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

operators began applying this technique commercially in North Dakota's Bakken Shale and Texas's Austin Chalk formations.[92] 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.[93] 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 more efficient and safer drilling, with the result being an even more favorable benefit-to-cost ratio.[94]

The above description of fracking and drilling technologies allows some appreciation of the web of technological developments that helped spur the shale gas boom. But any such appreciation is only a beginning. Many additional innovations underlie the boom and help explain comparison of modern wellheads to "high-tech factories."[95] New or improved technologies in locating, drilling, and fracturing for oil and gas include, among others, (1) 3D seismic imaging techniques to locate areas of abundant gas and to better understand the location of faults or of dips or rises in shale formations themselves,[96] techniques that have benefited from advances in computing and that draw on technology originally developed to track submarines;[97]

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until the early 1980's"); WANG & KRUPNICK, *supra* note 13, at 10 (also noting the lack of government involvement in horizontal drilling).

92 U.S. ENERGY INFO. ADMIN., *supra* note 84, at vii.

93 ANDREWS ET AL., *supra* note 72, at 19.

94 Pratt, *supra* note 87; *see also Formation Evaluation Advances: An Integrated Focus*, WEATHERFORD MAG., May 2012, at 11, 12, http://www.weatherford.com/dn/WFT196437; *cf. Drilling Dynamic Sensors and Optimization*, SCHLUMBERGER, http://www.slb.com/~/media/Files/drilling/brochures/mwd/drilling_dynamics_sensors_opt_br.ashx (last viewed Mar. 5, 2015) (observing that various forms of downhole sensing allow operators to avoid various drilling failures and thus reduce costs).

95 *The Petrostate of America*, *supra* note 51, at 10.

96 *See* Bowker, *supra* note 83, at 13 (testifying to the value of "[e]xcellent structural mapping" because "wells located on structural flexures or near major faults are less productive"); Murray Roth, *Unconventional Reservoirs Require Unconventional Approach to Integrate, Interpret Data*, AM. OIL & GAS REPORTER (Sept. 2010), *available at* https://www.transformsw.com/wp-content/uploads/2013/05/Unconventional-Reservoirs-Require-Unconventional-Approach-To-Integrate-Interpret-Data-2010-American-Oil-and-Gas-Reporter-Roth.pdf (noting how 3D seismic imaging can help to identify the particular fracturing "sweet spots"—in shale areas with particular rock characteristics that make fracturing more efficient—and how understanding the overall "thickness" of a shale is often not sufficient for effective shale production, as operators must identify key characteristics of the shale in addition to faults, including portions of the shale where fracturing will most likely create "permeability paths").

97 WANG & KRUPNICK, *supra* note 13, at 10, 13–14 (describing horizontal drilling, hydraulic fracturing, and 3D seismic mapping as the three technologies that spurred the boom); Kevin Begos, *Fracking Developed*

(2) "microseismic fracturing mapping," which typically uses a monitoring well to study the "height, length, orientation, and other attributes of induced fractures";[98] (3) equipment that isolates portions of a lateral wellbore and thereby enables increased fracturing of the rock around a well;[99] (4) polycrystalline drill bits with artificial diamond surfaces[100] that are particularly well suited to drilling hard rock;[101] (5) "flexible coiled tubing, continuously unreeled from a giant spool," that, during the completion process, can replace rigid well pipe and eliminate the need to interrupt use of a drill while new "sections of pipe are screwed together";[102] (6) friction reducers for fracking fluids;[103] and (7) "smaller and lighter" drilling rigs that are easier to transport between well pads.[104] In short, an ever-expanding multiplicity of technological developments have helped increase yields or reduce costs associated with the exploitation of shale gas formations, thereby enabling the favorable cost–benefit projections for producers that have spurred the shale gas boom.

II. INFRASTRUCTURE AND MARKETS BEYOND THE WELLHEAD

Despite the shale gas boom's multifarious technological backdrop, its triggering is often described as the work of a single man. After expending millions of dollars over a time period of nearly two decades,[105] the entrepreneurial George Mitchell ultimately saw his efforts to exploit the Barnett Shale bear fruit: by the late 1990s, his company had developed an

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with Decades of Government Investment, HUFFINGTON POST (Nov. 23, 2012, 5:12 AM EST), http://www.huffingtonpost.com/2012/09/23/fracking-developed-government_n_1907178.html ("[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 bit was, thousands of feet underground.").

98 WANG & KRUPNICK, *supra* note 13, at 14.

99 *See* CLARK ET AL., *supra* note 65, at 3 ("Approximately 1,000 feet of wellbore is hydraulically fractured at a time, so each well must be hydraulically fractured in multiple stages, beginning at the furthest end of the wellbore.").

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

101 BURWEN & FLEGAL, *supra* note 50, at 6.

102 Pratt, *supra* note 87.

103 *See* HONG SUN ET AL., SOC'Y OF PETROL. ENG'RS, SPE 139480, A NONDAMAGING FRICTION REDUCER FOR SLICKWATER FRAC APPLICATIONS (2011) (discussing new friction reducers that enable better production).

104 Al Pickett, *Technologies, Methods Reflect Industry Quest to Reduce Drilling Footprint*, AM. OIL & GAS REP. (July 2010), http://www.oilandgasbmps.org/docs/GEN170-reducedrillingfootprint.pdf.

105 *See* WATERS ET AL., *supra* note 86, at 1 ("Development of the Barnett Shale in the Ft. Worth basin began in 1981 with the drilling of the Mitchell Energy C.W. Slay #1.").

approach to hydraulic fracturing that could yield surprising quantities of gas relative to cost.[106]

This story is largely true. Mitchell was an innovator of remarkable persistence, and he drew attention to the potential for shale gas production and for the combined use of two distinct techniques that had been deployed piecemeal over time. After years of failed trial and error, he and his independent production company, Mitchell Energy and Development, succeeded in "crack[ing] the Barnett's code"[107] through a technique of slickwater fracturing that used formulas for fracking fluids remarkable for their relative simplicity.[108] In combination with horizontal drilling, the other leg of the Mitchell synthesis, slickwater fracturing promised to make shale gas production commercially viable on a broad scale, rather than the more limited scale on which Mitchell's shale gas production had previously occurred.[109] When natural gas prices rose in the early 2000s,[110] Mitchell's example, which

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[106] *See* DAN B. STEWARD, THE BARNETT SHALE PLAY: PHOENIX FOR THE FORT WORTH BASIN, A HISTORY 124–29 (Frank Paniszczyn ed., 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").

[107] YERGIN, *supra* note 13, at 327.

[108] Bowker, *supra* note 83, at 8 (affirming that "[w]ater fracs . . . were a radical concept" for the Barnett Shale "because the general consensus among completion engineers was that as much proppant (sand) as economically possible had to be placed in the Barnett" and "un-gelled water can carry very little" proppant). 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* SUN ET AL., *supra* note 103 ("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."); Silver, *supra* note 13 ("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* WATERS ET AL., *supra* note 86, 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."); Cahoy et al., *supra* note 26, at 285 (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%"). *See generally* Wiseman, *supra* note 5, at 744 n.60 (describing older gel-based and high-sand-volume techniques and providing sources).

[109] *See* Thomas W. Merrill, *Four Questions About Fracking*, 63 CASE W. RES. L. REV. 971, 973 (2013) ("After a long period of trial and error, an independent gas producer named George Mitchell . . . figured out the right combination of horizontal drilling, pressure, and proppants to get the gas flowing out of shale.").

[110] *See* U.S. ENERGY INFO. ADMIN., U.S. DEP'T OF ENERGY, DOE/EIA-0383, ANNUAL ENERGY OUTLOOK 2014 WITH PROJECTIONS TO 2040, at MT-21 to MT-23 & figs.MT-39 to MT-44 (2014), http://www.eia.gov/forecasts/aeo/pdf/0383(2014).pdf (providing graphs showing how U.S. production of shale gas took off in the middle of the first decade of the twenty-first century, a period when natural gas prices spiked upward and oil prices consistently rose).

culminated in the sale of Mitchell Energy to Devon Energy for $3.5 billion in 2002,[111] became irresistible.[112]

Nonetheless, Mitchell himself would likely have disclaimed this tale's simplicity. Far from being an isolated innovator, he actively sought and used private and public collaborators,[113] and he applied for and received federal incentive pricing for gas from the Barnett Shale.[114] Private partners were also critical for Mitchell's success. In particular, Mitchell Energy's long-term contract to supply Natural Gas Pipeline of America was a major impetus behind Mitchell's interest and persistence in developing the Barnett.[115] Moreover, a variety of other factors rooted in government support for innovation and natural gas markets were essential drivers of the technological revolution behind the shale gas boom. Of most immediate interest, changing national approaches to oil and gas regulation of pipelines and pricing reshaped potential markets for natural gas in ways that likely accounted for Mitchell's being active in the Barnett Shale at all.

A. Pipelines and "Pipeline Neutrality"

The availability of pipeline infrastructure centrally affects incentives to produce oil and gas. Generally speaking, fossil fuels are extracted in locations where they are abundant, and they must then be transported to the areas of

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111 YERGIN, *supra* note 13, at 328.

112 J. DANIEL ARTHUR, BRUCE LANGHUS & DAVID ALLEMAN, ALL CONSULTING, AN OVERVIEW OF MODERN SHALE GAS DEVELOPMENT IN THE UNITED STATES 4–5 (2008), 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).

113 *See infra* text accompanying notes 114–15.

114 *See* WANG & KRUPNICK, *supra* note 13, 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).

115 *See* STEWARD, *supra* note 106, at 44 (observing that Mitchell Energy's "NGPL contract in the North Texas area" provided critical "price guarantees"); WANG & KRUPNICK, *supra* note 13, at 16 (stating that contractual obligations to NGPL provided an "initial incentive for Mitchell Energy to develop the Barnett play").

highest demand.[116] For oil and gas, such transport commonly comes via pipelines.[117]

But the need for pipelines leads to classic problems of mismatch between group interests and individual capacities or incentives. Pipelines, particularly long interstate pipelines, can be expensive to build, and successful construction of interstate pipelines in the United States had historically required navigation of multiple states' policies on siting and land acquisition, as well as the hazard of potentially inconsistent regulation even after construction.[118] Producers could lack either the resources or incentive to run this gauntlet individually, and even if a private entity succeeded in constructing an interstate pipeline, the pipeline might be closed—or accessible only irregularly or at exorbitant cost—to others.[119] The federal government addressed these problems by regulating prices associated with the use of interstate pipelines[120] and by providing federal siting and eminent domain authority[121] to ease the process of construction. Eventually, the federal government also required open access to pipelines, thus enabling more competition in the production of gas for remote markets.[122] By the late 1990s, these changes had converged to create abundant pipeline capacity that, combined with updated pricing policies, helped spur new natural

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116 *See* Richard J. Pierce, Jr., *Reconstituting the Natural Gas Industry from Wellhead to Burnertip*, 9 ENERGY L.J. 1, 4 (1988) (noting that when interstate pipelines began to be developed, "the available supplies of natural gas were in different states than the major population and industrial centers where demand for gas was large and growing").

117 *Id.* ("[G]as can be transported economically only by pipeline."); *Refinery Receipts of Crude Oil by Rail, Truck, and Barge Continue to Increase*, U.S. ENERGY INFO. ADMIN. (July 17, 2013), http://www.eia.gov/todayinenergy/detail.cfm?id=12131 (noting that half of the crude oil received by U.S. refineries flows through pipelines, although transport by barge, truck, and rail is growing).

118 *See* Alexandra B. Klass & Danielle Meinhardt, *Transporting Oil and Gas: U.S. Infrastructure Challenges*, 100 IOWA L. REV. (forthcoming 2015) (manuscript at 36), *available at* http://ssrn.com/abstract=2410977 ("Consuming and producing states regularly imposed regulations on pipelines that were inconsistent . . . ."); Pierce, *supra* note 116, at 5 (noting state policies that served as barriers to interstate pipelines).

119 *See* Robert J. Michaels, *The New Age of Natural Gas: How the Regulators Brought Competition*, REGULATION, Winter 1993, at 68, 68–69 (noting that the Natural Gas Act of 1938 capped the prices that interstate pipelines could charge for the use of their lines but did not require open access, and pipelines typically purchased "gas . . . at the wellhead and, passing on the purchase price, resold it to distributors" rather than giving "producers or users" direct access to pipelines); Pierce, *supra* note 116, at 6–7 (observing that pipelines "were not obligated to provide third parties access to their facilities" and noting their "precluding" of beneficial transactions).

120 *See infra* note 133 and accompanying text.

121 *See infra* notes 133–34 and accompanying text.

122 *See infra* note 143 and accompanying text.

gas production for sale to out-of-state markets.[123] This transition was not quick, however; it was the culmination of several historic innovations and policy changes.

As Alexandra Klass and Danielle Meinhardt describe, improved technologies for welding, stronger pipeline materials, and better compressors necessary for transporting natural gas long distances matured shortly after discovery of large natural gas fields in Kansas, Oklahoma, and Texas in 1918.[124] In 1924, the U.S. Supreme Court declared that states could not regulate the prices charged by interstate pipelines,[125] thereby removing one set of obstacles to pipeline construction and operation. In the wake of these developments, "twelve major gas transportation systems" emerged between 1927 and 1931.[126] But the constituent pipelines did not form a truly national network, and they left the Northeast, for example, in a common state of shortage.[127] Further, in the absence of federal regulation, abolition of state regulation had opened a regulatory gap.[128] Interstate pipeline companies, which purchased gas from producers and sold the gas to instate and out-of-state consumers, became local monopsonists in dealing with producers and oligopolists in dealing with consumers (typically simply called monopolists, although in some cases more than one pipeline was available within a region), exercising their resulting pricing power to their own advantage.[129]

In the 1930s, the pricing practices of pipeline companies, combined with an abundance of gas in and around Texas and relative scarcity in the Northeast, induced a diverse group of lobbyists to demand federal intervention.[130] This group included a coalition of cities that wanted better access to gas, the coal industry that believed federal regulation would in fact "drive up prices," and producers and consumers who suffered from the pipeline companies' pricing

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[123] *Cf.* Michael J. Doane, R. Preston McAfee & Michael A. Williams, *Evaluating and Enhancing Competition in the Interstate Natural Gas Transportation Industry*, 44 NAT. RESOURCES J. 761, 768 (2004) (noting the interconnection and integration of pipelines by the 1990s and expanded regional and national access to gas).

[124] Klass & Meinhardt, *supra* note 118 (manuscript at 36).

[125] Missouri v. Kan. Natural Gas Co., 265 U.S. 298 (1924).

[126] Klass & Meinhardt, *supra* note 118 (manuscript at 36).

[127] *Id.* (manuscript at 38) (observing that "from 1932 until World War II" the "Northeastern market potential was immense, but no major pipelines existed to bring gas to that populous region").

[128] *See id.* (manuscript at 37) (discussing regulation arising in the aftermath of *Kansas Natural Gas Co.*).

[129] *See* Pierce, *supra* note 116, at 4–6.

[130] Klass & Meinhardt, *supra* note 118 (manuscript at 37).

practices.[131] At the recommendation of the Federal Trade Commission, Congress passed the Natural Gas Act of 1938, providing for federal authority over the interstate transportation of natural gas, among other interstate gas activities.[132] The Federal Power Commission (FPC) and, later, the Federal Energy Regulatory Commission (FERC) regulated natural gas prices,[133] approved certificates for new interstate pipelines,[134] and granted eminent domain authority for the siting of pipelines,[135] allowing an interstate network of natural gas pipelines to flourish.[136]

Nonetheless, access to pipelines remained limited. The FPC capped the price that natural gas pipelines could charge for the natural gas they purchased, transported, and sold, but these companies were not required to allow producers to use the pipelines.[137] Moreover, the FPC had long "refused to allow pipelines to transport gas sold directly by producers to end-users" because of the Commission's inability to regulate prices for such sales.[138] As a result, pipelines typically purchased gas from producers and resold it, and a number of producers had only limited access to markets.[139] Beginning in 1976, however, the FPC began to grant a limited number of producers direct access to consumers, allowing case-by-case approvals for pipeline transport of gas sold directly from producers to "high priority" commercial and industrial consumers.[140] Two additional orders (now from FERC) in 1979 further supported sales directly from producers to consumers: Order 27 provided blanket approvals for pipelines to transport gas sold from producers directly to

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131 *Id.*

132 Natural Gas Act, ch. 556, 52 Stat. 821 (1938) (codified as amended at 15 U.S.C. §§ 717–717z (2012)).

133 *Id.* § 4(a), 52 Stat. at 822.

134 *Id.* § 7(c), 52 Stat. at 825.

135 *Id.* § 7(a), 52 Stat. at 824.

136 Klass & Meinhardt, *supra* note 118 (manuscript at 36) ("Between 1927 and 1931 about twelve major gas transportation systems developed, all over 200 miles long.").

137 *See* Pierce, *supra* note 116, at 24 ("[B]y regulating pipeline sales but not pipeline transportation, Congress and the FERC had created artificially pipeline monopoly power . . . .").

138 Robert C. Means & Robert S. Angyal, *The Regulation and Future Role of Direct Producer Sales*, 5 ENERGY L.J. 1, 5 (1984).

139 *See* Michaels, *supra* note 119, at 69 ("[I]nstead of transporting gas owned by producers or users, pipelines purchased it at the wellhead and, passing on the purchase price, resold it to distributors."); Richard J. Pierce, Jr., *Natural Gas Regulation, Deregulation, and Contracts*, 68 VA. L. REV. 63, 79 (1982) (explaining that from the 1930s through 1950s, "monopsony conditions prevailed in much of the market: a single pipeline provided the sole market outlet for a number of competing producers").

140 Certification of Pipeline Transportation Agreements, 40 Fed. Reg. 41,760, 41,760 (Aug. 28, 1975); *see also* Sean J. McNulty, Comment, *Freeing the Captives: Nondiscriminatory Access to Transportation in the Interstate Natural Gas Market*, 47 U. PITT. L. REV. 843, 849 (1986) (describing the order).

critical agricultural users, hospitals, and schools,[141] and Order 30 granted similar pipeline transport authority for natural gas sold directly from producers to consumers in lieu of scarce fuel oil.[142] Later, in 1985, FERC Order 436 gave pipelines "expedited," blanket approval to enter into open-access gas transportation contracts with third-party shippers if the pipelines accepted the risk for the pipeline (rather than passing costs to existing customers) and met other conditions.[143] Finally, in 1992, FERC Order 636 dramatically restructured the pipeline business, requiring the functional separation of interstate pipeline companies' gas purchasing and selling activities from their transportation business[144] and mandating that these companies offer open-access service.[145] Under Order 636, pipeline companies could not favor their own gas in the operation of pipelines,[146] and they had to provide electronic pricing and service information so that their terms were transparent.[147]

When producers, including smaller independents like Mitchell Energy, could directly access larger numbers of distant purchasers—particularly those in the relatively gas-poor Northeast—they could anticipate lucrative returns

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141 Certification of Pipeline Transportation for Certain High Priority Uses, 44 Fed. Reg. 24,825, 24,825, 24,828 (Apr. 27, 1979) (allowing "the transportation of natural gas sold by a producer to an eligible user" and defining eligible uses).

142 Transportation Certificates for Natural Gas for the Displacement of Fuel Oil, 44 Fed. Reg. 30,323, 30,329 (May 25, 1979) (exempting pipelines from previously-required FERC approval of transportation of natural gas from producers—"first sales"—to suppliers of natural gas who would otherwise use fuel oil); *see also* McNulty, *supra* note 140, at 850 (describing the order).

143 *See* Regulation of Natural Gas Pipelines After Partial Wellhead Decontrol, 50 Fed. Reg. 42,408, 42,467 (Oct. 18, 1985) (establishing "Optional Expedited Certificates" that provided blanket authorizations for pipelines to transport gas for third-party shippers if pipelines agreed to take on the risk of building the pipeline and met other conditions); *see also* 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) (describing the order).

144 Pipeline Service Obligations and Revisions to Regulations Governing Self-Implementing Transportation; and Regulation of Natural Gas Pipelines After Partial Wellhead Decontrol, 57 Fed. Reg. 13,267, 13,281 (Apr. 16, 1992) (requiring "firm and interruptible transportation services to be provided unbundled from firm and interruptible sales").

145 *See id.* at 13,281–82 (requiring "an open-access pipeline that offers firm and interruptible transportation services to provide those transportation services . . . on a basis that is equal in quality for all gas supplies, whether purchased from the pipeline or elsewhere" and allowing "firm" shippers—those who commit to using a certain amount of pipeline space—to "release unwanted capacity to those desiring capacity").

146 *Id.* at 13,288 (prohibiting pipeline companies from "creating an advantage to the pipeline as seller or to its marketing affiliate" in "operational provisions").

147 *See id.* at 13,281 (requiring "a pipeline to provide all shippers equal and timely access to certain information through the use of electronic bulletin boards").

even from more-expensive, less-accessible gas reserves that required sophisticated technologies for extraction. The natural result was incentive to exploit such reserves. As "commons" theorists might hasten to point out,[148] it seems more than mere coincidence that FERC's adoption of a "pipeline neutrality" policy was followed within about a decade by Mitchell Energy's breakthroughs and subsequent market recognition of shale gas's commercial potential.[149]

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 formations.[150] A Supreme Court decision in the 1950s forced the FPC, and later FERC, to regulate all prices of gas at the wellhead if that gas was eventually to be sent interstate.[151] Such regulation effectively discouraged the overall production of natural gas, including unconventional natural gas.[152] As the interstate price was capped, producers commonly had insufficient incentive to sell gas to distant interstate users who badly needed the gas.[153] Likewise, price caps could

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148 *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.").

149 Interview by Michael Shellenberger with Dan Steward, Former Mitchell Energy Vice President, (Dec. 12, 2011), *available at* http://thebreakthrough.org/archive/interview_with_dan_steward_for [hereinafter Shellenberger Interview] (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).

150 Pierce, *supra* note 116, at 11–16 (describing and criticizing Natural Gas Policy Act pricing policies, including policies that maintained price ceilings on "old," conventional gas that already was being produced and raised or eliminating ceilings for other types of gas); Pierce, *supra* note 139, at 68 ("Lower ceilings were established for 'old gas,' or gas flowing from existing wells, reflecting the Commission's determination that gas would continue to flow from existing wells at roughly constant costs. Higher ceilings were established for 'new gas,' or gas produced from wells drilled later, to preserve exploration incentives.").

151 Phillips Petrol. Co. v. Wisconsin, 347 U.S. 672 (1954); *see also* Pierce, *supra* note 139, at 66 (discussing the Supreme Court decision and FERC's previous interpretation of its authority).

152 Pierce, *supra* note 139, at 69 ("There is no longer serious doubt that regulation of gas producer prices was the dominant factor responsible for the gas shortage that caused significant economic dislocations in the United States from 1969 through 1978.").

153 *See supra* note 152; *see also* ENERGY CHARTER SECRETARIAT, PUTTING A PRICE ON ENERGY: INTERNATIONAL PRICING MECHANISMS FOR OIL & GAS 111 (2007) ("It gradually became apparent that wellhead price controls in their then-existing form were unworkable. By the late 1960s, the system was beginning to develop serious supply problems, and by the early 1970s gas shortages became increasingly severe, leading to supply curtailments of large customers."); PAUL W. MACAVOY, THE NATURAL GAS

eliminate prospects for profit from more marginal reserves, including unconventional gas reserves, for which the private cost–benefit calculus was not among the most favorable.[154]

Government attempts to reform gas markets followed. In the 1960s, FERC attempted to enhance the production of domestic gas without causing excessive inflation, 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.[155] But shortages remained, and an increasingly complex pricing scheme coincided with an overall decline of the "total quantity of gas made available to the market."[156] In the Natural Gas Policy Act of 1978, Congress later helped stimulate the production of "deep" gas and "tight" gas—resources that tended to require unconventional technologies like horizontal drilling (and ultimately fracturing)—by allowing producers to charge higher interstate rates for gas produced from unconventional formations.[157] In 1989, Congress fully deregulated the price of natural gas at the wellhead, albeit with several transition years for price deregulation to take complete effect.[158] Deregulation allowed all producers to charge market prices for all types of gas.[159]

In short, gradual changes in pricing policies, combined with regulations enabling the siting and construction of pipelines and requiring open access to these pipelines, created the national market that was necessary to support

MARKET: SIXTY YEARS OF REGULATION AND DEREGULATION 1–2 (2000) ("Federal regulatory policy in the 1960s and 1970s placed limits on gas prices that caused significant nationwide shortages, and in response, new policy in the late 1970s then caused surpluses that closed down production facilities and led to dumping gas in spot markets.").

154 *Cf.* Regulation of Natural Gas Pipelines After Partial Wellhead Decontrol, 50 Fed. Reg. 42,408, 42,416 (Oct. 18, 1985) (noting various market distortions caused by price ceilings and that when Congress deregulated the price that could be charged for alternative gas supplies and gas found very deep underground, "[p]rices rose sharply," and "[m]any millions of dollars were spent on exploring for gas that the market seemed to be saying could be sold" at a high price); Pierce, *supra* note 139, at 68–69 (in discussing the regional—"area"—rates established for natural gas prices at the wellhead, and the higher price allowed to be charged for newly drilled gas in an effort to encourage production, noting that "to avoid discouraging production would have required ongoing company-by-company cost determinations").

155 Pierce, *supra* note 139, at 68.

156 *Id.* at 69.

157 Natural Gas Policy Act of 1978, Pub. L. No. 95-621, 92 Stat. 3350, *amended by* Natural Gas Wellhead Decontrol Act of 1989, Pub. L. No. 101-60, 103 Stat. 157; *see* Hinton, *supra* note 6, at 233 (noting that the Natural Gas Policy Act of 1978 "offered natural gas producers substantial price incentives to find and produce gas from riskier, more expensive exploration").

158 § 2(b), 103 Stat. at 158.

159 *Id.* § 2(a), 103 Stat. at 157–58 (providing that "maximum lawful prices" of gas should cease to apply).

high-priced drilling and fracturing by a multitude of independent producers,[160] smaller players that, unlike "major multinational companies such as ExxonMobil," are generally "not vertically integrated" and "are usually regionally focused."[161] By the early 1990s, the foundations for a vibrant national market in natural gas—open-access interstate pipelines and favorable policies on pricing—were in place.

III. GOVERNMENT SUPPORT

Government contributions to the fracking revolution did not stop with transport and market infrastructure. Federal and state governments also supported relevant technological and commercial developments through a variety of frequently more targeted means, including direct government research, government funding, collaborative research projects and public–private partnerships, tax preferences, and regulatory exemptions.[162] This Part discusses such mechanisms and their roles in fostering the shale gas boom.

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 Ford to create the Energy Research and Development Administration (ERDA) in 1976, with promotion of "Unconventional Gas Research" as one of its goals.[163] ERDA promptly began collaborating with universities and industry to "develop[] an

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160 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. *See* Hinton, *supra* note 6, at 233 (observing that, after the Natural Gas Policy Act of 1978, "[t]hose willing to focus on natural gas and willing to try expensive, marginally profitable projects that would likely be rejected by the majors' boards of managers finally had federal blessing to try their luck").

161 *Id.* at 229.

162 *See infra* Part III.C. *See generally Federal Financial Support for Energy Technologies: Assessing Costs and Benefits: Hearing Before the Subcomm. on Energy of the H. Comm. on Sci., Space & Tech.*, 113th Cong. 20 (2013) (statement of Terry Dinan, Senior Analyst, Congressional Budget Office), *available at* http://www.cbo.gov/sites/default/files/cbofiles/attachments/03-12-EnergyTechnologies.pdf (describing different financial mechanisms for government support).

163 BURWEN & FLEGAL, *supra* note 50, at 2 ("In 1976, Congress funded the Energy Research and Development Administration . . . to launch the Unconventional Gas Research (UGR) program.").

inventory of the unconventional gas resources across several regions,"[164] and ERDA's 1977 successor, the DOE, continued such work.[165]

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.[166] 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."[167] Building from these successes, EGSP focused on the Devonian shales of the Appalachian, Michigan, and Illinois Basins.[168] Through EGSP, ERDA worked with industry, universities, and state geological surveys[169] "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.[170] The EGSP supported the drilling of about thirty-five experimental wells that demonstrated, among other things, possibilities for horizontal drilling.[171] The EGSP also supported "theoretical and experimental research on hydraulic fracturing by Lawrence Livermore Laboratory" and collaborative work on fracturing by the Stanford Research

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164 *Id.*

165 NAT'L RESEARCH COUNCIL, *supra* note 34, at 1.

166 *Id.* at 201.

167 NAT'L ENERGY TECH. LAB., U.S. DEP'T OF ENERGY, SHALE GAS: APPLYING TECHNOLOGY TO SOLVE AMERICA'S ENERGY CHALLENGES 5 (2011), http://www.netl.doe.gov/file%20library/research/oil-gas/Shale_Gas_March_2011.pdf [hereinafter NETL REPORT].

168 *See* NAT'L ENERGY TECH. LAB., U.S. DEP'T OF ENERGY, DOE'S UNCONVENTIONAL GAS RESEARCH PROGRAMS 1976–1995, at 16 (2007), http://www.netl.doe.gov/KMD/cds/disk7/disk2/Final%20Report.pdf (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").

169 Leo A. Schrider & Robert L. Wise, *Potential New Sources of Natural Gas*, 32 J. PETROLEUM TECH. 703, 703–04 (1980).

170 NAT'L RESEARCH COUNCIL, *supra* note 34, at 201; *cf.* Schrider & Wise, *supra* note 169, 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 SYS. PLANNING DIV., TRW, INC., CORING AND LOGGING PLAN: EASTERN GAS SHALES PROJECT (1977), *available at* http://www.netl.doe.gov/kmd/cds/disk7/disk1/EGS%5CCoring%20and%20Logging%20Plan,%20Eastern%20Gas%20Shales%20Project.pdf.

171 BURWEN & FLEGAL, *supra* note 50, 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. DEP'T OF INTERIOR GEOLOGICAL SURVEY, NO. 81-598, 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.

Institute, Sandia Laboratories, and others.[172] In total, the EGSP spent about $185 million in 2011 dollars,[173] with peak spending occurring during the first several years of the program.[174]

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.[175] But the EGSP's contributions came at critical times when the possibilities for exploitation of shale gas reserves were poorly understood,[176] when large oil and gas companies were reducing investment in research and development,[177] and when, as has continued to be the case,[178] the field of unconventional gas recovery was largely dominated by relatively small independents with limited budgets for research and development.[179] As one set of commentators concluded, "The 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."[180] Resource estimates of

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172 Schrider & Wise, *supra* note 169, at 709.

173 BURWEN & FLEGAL, *supra* note 50, at 3.

174 *Id.* (reporting that the EGSP's peak budget was $18 million—or $47 million in 2011 dollars—in 1979); NAT'L RESEARCH COUNCIL, *supra* note 34, 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." (citation omitted)).

175 *Cf.* MIT ENERGY INITIATIVE, THE FUTURE OF NATURAL GAS: AN INTERDISCIPLINARY MIT STUDY 160 (2011), https://mitei.mit.edu/system/files/NaturalGas_Report.pdf [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 R&D, has historically had very small programs dedicated to natural gas exploration, production, transportation and use."); NAT'L RESEARCH COUNCIL, *supra* note 34, 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 . . . .").

176 *See* NAT'L RESEARCH COUNCIL, *supra* note 34, 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.").

177 BURWEN & FLEGAL, *supra* note 50, at 5 ("Starting in the early 1980s, major oil and gas companies began to decrease their research and development spending . . . .").

178 Hinton, *supra* note 6, at 235 ("It is significant that as shale production has taken off in many areas, independents still dominate shale action, greatly outnumbering and outspending major and national oil companies.").

179 *See* BURWEN & FLEGAL, *supra* note 50, 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."); NAT'L RESEARCH COUNCIL, *supra* note 34, 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").

180 BURWEN & FLEGAL, *supra* note 50, at 2.

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.[181]

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."[182] From the start, a goal of the EGSP was to "encourage[] private industry to initiate and direct R&D projects by sharing the risks and costs of development."[183] In turn, GRI was perhaps the leading embodiment of a public–private partnership in this 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 underinvested in research and development.[184] 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."[185] GRI's peak annual budgets thus exceeded the total amount spent by the EGSP during the decade and a half of its existence.[186] Moreover, of likely significance for businesses seeking assurance in making long-range plans, GRI's funding was relatively stable and "independent of annual Congressional appropriations."[187]

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[181] Loren Steffy, *How Much Did the Feds Really Help with Fracking?*, FORBES (Oct. 31, 2013, 9:21 AM), http://www.forbes.com/sites/lorensteffy/2013/10/31/how-much-did-the-feds-really-help-with-fracking/.

[182] MIT STUDY, *supra* note 175, app. 8A, at 3. 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. *Id.* app. 8A, at 5–6. But GRI lasted through the late 1990s, when Mitchell made his critical breakthrough with slickwater hydraulic fracturing.

[183] Schrider & Wise, *supra* note 169, at 704.

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

[185] BURWEN & FLEGAL, *supra* note 50, at 4.

[186] *See supra* text accompanying notes 173–74.

[187] MIT STUDY, *supra* note 175, app. 8A, at 5.

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.[188] Overall, GRI's work had a more applied focus than the DOE's work,[189] 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."[190] But the work of the DOE and GRI was not purely complementary: they sometimes collaborated directly, as in coordinating with private companies to fund the drilling of experimental horizontal wells.[191] 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.[192]

DOE and GRI funding and leadership not only helped set the technological agenda for improvements in natural gas extraction but also encouraged information sharing. As a condition of federal support for GRI, its projects were required to publish all findings, and industry partners were required to surrender claims to intellectual property rights in these findings.[193] "Moreover, FERC made GRI indifferent to [intellectual property] royalties by subtracting any royalties from FERC funding; this ensured that GRI focused on technology diffusion as much as possible, rather than [on] support[ing] itself from licensing income."[194]

Quite generally, GRI appears to have helped foster an environment favorable to adoption of new technologies by independent producers, with whom GRI collaborated extensively. In 1991, Mitchell Energy began working directly with the DOE and GRI, joining with them over a period of several years to drill Mitchell's first horizontal well in the Barnett and, more generally,

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188 *Id.* at 160.

189 BURWEN & FLEGAL, *supra* note 50, at 4 ("DOE and GRI complemented each other; 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.").

190 MIT STUDY, *supra* note 175, app. 8A, at 5.

191 BURWEN & FLEGAL, *supra* note 50, at 2 ("Experimental horizontal 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 175, app. 8A, at 4 (noting that GRI "sometimes provid[ed] substantial industry match into the smaller DOE programs").

192 MIT STUDY, *supra* note 175, app. 8A, at 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.").

193 BURWEN & FLEGAL, *supra* note 50, at 5.

194 *Id.*

to develop knowledge and techniques that would prove useful later.[195] More generally, the GRI board apparently showed a solid capacity to respond to input from industry.[196] Mitchell was on the GRI board, and Mitchell's persistence was "generally credited with establishing the GRI focus" on unconventional natural gas.[197] 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.[198]

In addition to helping individual operators like Mitchell, DOE and GRI supported development of a number of significant technologies. DOE and GRI contributions to demonstrations and development of techniques of horizontal drilling and hydraulic fracturing have already been noted.[199] Other key technologies to which DOE and GRI contributed were polycrystalline diamond drill bits,[200] measurement and logging of critical data while drilling,[201] and 3D seismic imaging.[202]

The story of DOE's support of innovation in drill bits is of particular interest because it illustrates 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

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195 *See* Shellenberger Interview, *supra* note 149 (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" in the Barnett, map cracks, and work on "re-fracks of shale wells"); *supra* note 20.

196 Burnett et al., *supra* note 184, at 46 ("GRI uses a comprehensive strategic planning and analysis approach with wide-ranging advisory input to develop its annual five-year plan." (citation omitted)).

197 MIT STUDY, *supra* note 175, app. 8A, at 5.

198 BURWEN & FLEGAL, *supra* note 50, at 4–5.

199 *See supra* text accompanying notes 188–95.

200 *See supra* text accompanying note 100.

201 NAT'L RESEARCH COUNCIL, *supra* note 34, at 195 (noting that the DOE "supported a field demonstration of [mud pulse telemetry] in its very early and critical phase of development"); NETL REPORT, *supra* note 167, at 6 (suggesting that modern directional drilling technologies such as electromagnetic telemetry had their "roots in DOE research from the 1980s and 90s.").

202 *See* WANG & KRUPNICK, *supra* note 13, at 13–14 (discussing a DOE seismic imaging program that began in 1988, DOE-sponsored mapping research at Los Alamos National Laboratory, and a "DOE Multiwell Site experiment in Colorado"); *cf.* NAT'L RESEARCH COUNCIL, *supra* note 34, 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 operator . . . is a useful adjunct to a major private sector activity").

wells."[203] Fortuitously, the resulting polycrystalline diamond bits turned out to be tremendously useful in drilling oil and gas wells and lowered drilling costs substantially[204]—a development that was presumably of particular importance 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.[205]

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 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."[206] This tax credit, which Congress enacted as part of the Windfall Profits Tax Act of 1980,[207] generated tax savings of about $10 billion for operators between 1980 and 2002,[208] including about $760 million in savings in 1993 alone.[209] 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.[210] Even small operators who lacked substantial tax liabilities were able to benefit from the credits by engaging in tax equity financing transactions in which they

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203 GALLAHER ET AL., *supra* note 100, at 97.

204 *Id.* ("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." (citations omitted)).

205 *Id.* at 97–98 (crediting DOE with "significant contribution[s] 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 of PDC drill bits").

206 MIT STUDY, *supra* note 175, at app. 8A, at 5; *see also* YERGIN, *supra* note 13, at 326 ("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.").

207 BURWEN & FLEGAL, *supra* note 50, at 2.

208 Begos, *supra* note 97.

209 MIT STUDY, *supra* note 175, at app. 8A, at 5.

210 *See supra* text accompanying notes 173–74, 185–86.

"effectively 'sold' their credits to larger firms."[211] Once again, Mitchell Energy took advantage of the opportunity for government assistance, using tax credits to "help[] underwrite the cost of developing hydraulic fracturing."[212]

Beyond the now-defunct Section 29 credit, there are a wide variety of 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.[213] 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.[214] Many of these tax preferences are controversial[215]: the Obama Administration has repeatedly proposed repealing a number of them.[216] For purposes of this study, however, the key point is that, to the extent these more general tax preferences attracted investment either in shale gas extraction or in associated technologies,[217] they too contributed to the shale gas boom.

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211 BURWEN & FLEGAL, *supra* note 50, at 7.

212 Steffy, *supra* note 181.

213 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).

214 *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 of 42% 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); *see also* GILBERT E. METCALF, MANHATTAN INST. FOR POLICY RESEARCH, TAXING ENERGY IN THE UNITED STATES: WHICH FUELS DOES THE TAX CODE FAVOR? 5 tbl.2 (2009), http://www.manhattan-institute.org/pdf/eper_04.pdf (estimating effective tax rates of negative 13.5% for independent production companies and 15.2% for "integrated firms").

215 *See, e.g.*, MAURA ALLAIRE & STEPHEN BROWN, RESOURCES FOR THE FUTURE, ELIMINATING SUBSIDIES FOR FOSSIL FUEL PRODUCTION: IMPLICATIONS FOR U.S. OIL AND NATURAL GAS MARKETS 14 (2009), http://rff.org/RFF/Documents/RFF-IB-09-10.pdf ("[T]here is divergent opinion about the effects of such subsidies."); Johnson, *supra* note 214, at 573 ("The government should get out of the business of subsidizing oil and gas via the tax system.").

216 *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, CONG. RESEARCH SERV., R42374, OIL AND NATURAL GAS INDUSTRY TAX ISSUES IN THE FY2014 BUDGET PROPOSAL 2 (2013) (reporting that for the FY2014 budget proposal the Obama Administration proposed to eliminate various fossil fuel benefits).

217 *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.").

In particular, one of these tax preferences, the "percentage depletion allowance,"[218] is of interest because, since 1975, it has been available only for independent producers, operators that, as indicated before,[219] are non-vertically integrated "producers that do not have refining and retailing operations, and are unrelated to those that do."[220] Under the percentage depletion allowance, independent producers of oil and gas may "deduct against their gross receipts a depletion amount equal to 15% of their oil and gas revenue"—thereby effectively rendering that share of revenue free from tax.[221]

Percentage depletion can play a substantial role in generating an effective negative tax on production.[222] The Congressional Budget Office (CBO) has estimated that percentage depletion provided $900 million in tax relief in the 2011 fiscal year.[223] 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.[224]

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."[225] This allowance remains in effect and

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218 Johnson, *supra* note 214, at 581.

219 *See supra* text accompanying note 161.

220 Bogdanski, *supra* note 213, at 325. *Compare id.* (describing current provisions for percentage depletion), *with* 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"). *See generally* Walter J. Mead, *The Performance of Government in Energy Regulations*, 69 AM. ECON. REV. (PAPERS & PROC.) 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).

221 Bogdanski, *supra* note 213, at 325.

222 Johnson, *supra* note 214, at 581; *see also* METCALF, *supra* note 214, at 5 tbl.2 (estimating effective tax rates of negative 13.5% for independent production companies and 15.2% for "integrated firms").

223 CONG. BUDGET OFFICE, FEDERAL FINANCIAL SUPPORT FOR THE DEVELOPMENT AND PRODUCTION OF FUELS AND ENERGY POLICIES 2–3 (2012), http://www.cbo.gov/sites/default/files/cbofiles/attachments/03-06-FuelsandEnergy_Brief.pdf.

224 *See* WANG & KRUPNICK, *supra* note 13, 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.").

225 MOLLY F. SHERLOCK, CONG. RESEARCH SERV., R41227, ENERGY TAX POLICY: HISTORICAL PERSPECTIVES ON THE CURRENT STATUS OF ENERGY TAX EXPENDITURES 2–3 (2011); *see also* Bogdanski,

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.[226] 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."[227] Congress has specifically indicated that such costs include expenses from fracturing.[228] 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, "Integrated 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."[229]

Like percentage depletion, IDC deduction is viewed as a substantial tax preference. The CBO has estimated that in the 2011 fiscal year this allowance provided a total of $800 million in tax relief.[230] 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 know-how suggests that the IDC deductions likely provided substantial encouragement for the extraction techniques that are hallmarks of the fracking revolution. Consistent with this sense, the Western Energy Alliance, a trade association formerly known as the Independent Petroleum Association of Mountain States,[231] 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.[232] The Alliance specifically

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supra note 213, 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.").

226 SHERLOCK, *supra* note 225, at 3.

227 Hymel, *supra* note 217, at 49.

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

229 Bogdanski, *supra* note 213, at 326 (footnote omitted).

230 CONG. BUDGET OFFICE, *supra* note 223, at 3.

231 *About Western Energy Alliance*, W. ENERGY ALLIANCE, http://www.westernenergyalliance.org/alliance (last visited Mar. 5, 2015).

232 W. ENERGY ALLIANCE, INTANGIBLE DRILLING COSTS (IDC) AND OTHER DEDUCTIONS DRIVE INNOVATION AND JOB CREATION (2013), http://waysandmeans.house.gov/uploadedfiles/western_energy_

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."[233]

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 allowance for "tax-exempt bond-financed prepayments" for natural gas;[234] a deduction for the use of tertiary injectants, such as carbon dioxide, in old reservoirs to wring remaining resources out of them;[235] a "passive loss exception for working interests in oil and natural gas properties;"[236] and limited time periods for amortization of "geological and geophysical" expenses (seven years for large, integrated companies and two years for independents)[237] that allow for a higher annual deduction than might otherwise apply.[238] 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[239] "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."[240] 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

alliance_wg_comment.pdf (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).

233 *Id.*

234 SHERLOCK, *supra* note 225, 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 216, at 3.

235 PIROG, *supra* note 216, at 4.

236 *Id.*

237 Bogdanski, *supra* note 213, at 326.

238 PIROG, *supra* note 216, at 6–7. Last-in, first-out (LIFO) 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 214, 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 213, at 328 (footnotes omitted).

239 PIROG, *supra* note 216, 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).

240 Bogdanski, *supra* note 213, at 327.

landowners, suppliers, and drillers with economic interests in the future profits of their operations."[241]

In addition to the preceding host of forms of favorable treatment under federal tax law, drilling and fracturing operations have received and continue to enjoy state tax advantages. Most states place a severance tax on oil and gas when it is extracted, often in the range of three to twelve percent of the market value of the oil and gas sold.[242] Many of these states, however, exempt unconventional or "high-cost" gas from the tax.[243] 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.[244] Meanwhile, with agreement from the governor, Pennsylvania's legislature repeatedly refused to pass a severance tax on resource extraction.[245] By February 2012, when the Pennsylvania legislature finally agreed upon an

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241 *Id.* at 328. This doctrine treats the transactions in question—including transactions for services that are entirely complete—as nontaxable 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 214, at 579 (noting IRS embrace of the doctrine in 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 n.56; *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").

242 *See, e.g.*, LA. REV. STAT. ANN. § 47:633(7)(a), (c)(ii)(aa) (Supp. 2015) (12.5% tax on oil's "value at the time and place of severance" with temporary suspension of the tax for horizontally-drilled wells); MISS. CODE ANN. § 27-25-503(1)(b), (c)(1) (West Supp. 2013) (tax of 3% of "the value of the oil at the point of production" and 1.3% for oil from horizontally drilled wells for a limited time period); N.M. STAT. ANN. § 7-29-4(A)(1), (4) (West 2012) (tax of 3.75% of the taxable value of natural gas, but 2.45% for natural gas from "well workover" projects).

243 *See, e.g.*, SUSAN COMBS, TEX. COMPTROLLER OF PUB. ACCOUNTS, THE ENERGY REPORT 379 (2008) ("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."); *supra* note 242.

244 COMBS, *supra* note 243, at 68, 378.

245 Susan Phillips, *Corbett Defends Impact Fee over Severance Tax*, STATEIMPACT (June 14, 2013, 5:06 PM), http://stateimpact.npr.org/pennsylvania/2013/06/14/corbett-defends-impact-fee-over-severance-tax/.

impact fee instead,[246] the state had already issued more than ten thousand permits for unconventional wells.[247]

C. Regulatory Relief

Like taxes, regulations can impact the profitability of innovation-related activity, and governments have commonly used regulatory relief to try to spur investment. But at least in relation to the fracking revolution, the impact of such relief might be more marginal than is commonly assumed. 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 such as 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, the Department estimated that total compliance costs imposed through the rulemaking would be "between $75,002,050 and $96,636,950 annually."[248] Spread among approximately 1,751 Marcellus Shale wells drilled and fractured in 2011,[249] the estimated upper-bound cost was approximately $55,200 annually per well—an amount that is a small fraction of the more than $6 million that one unconventional well can cost,[250] although the total cost of regulatory compliance rises, of course, through annual accretion.

In any event, regulations, even those that arguably only hit margins, can risk discouraging development to a degree that policymakers find intolerable. For example, in 1988, the Environmental Protection Agency determined that oil and gas "exploration and production" wastes—most of the soil and rock cuttings, liquid wastes, used drilling fluids and muds, and other wastes

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246 58 PA. CONS. STAT. ANN. §§ 2301–2318 (West, Westlaw current through 2014 Reg. Sess.).

247 *Year to Date—Permits Issued by County and Well Type Report*, PA. DEP'T OF ENVTL. PROT., 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," select "All" for "REGION," select "Yes" for "UNCONVENTIONAL ONLY," and view final page of the resulting report) (last visited Mar. 5, 2015).

248 Environmental Protection Performance Standards at Oil and Gas Well Sites, 43 Pa. Bull. 7377 (Dec. 14, 2013), *available at* http://www.pabulletin.com/secure/data/vol43/43-50/2362.html.

249 Bureau of Oil & Gas Mgmt., *Wells Drilled*, PA. DEP'T OF ENVTL. PROTECTION (Dec. 5. 2011), http://www.dep.state.pa.us/dep/deputate/minres/oilgas/2011%20Wells%20Drilled.gif.

250 *Pad Drilling and Rig Mobility Lead to More Efficient Drilling*, U.S. ENERGY INFO. ADMIN. (Sept. 11, 2012), http://www.eia.gov/todayinenergy/detail.cfm?id=7910 ("EIA analysis of average Bakken, Eagle Ford, and Marcellus well-related expenses finds that total costs per horizontal well can vary between approximately $6.5 million and $9 million.").

produced at well sites—should not be regulated as hazardous wastes under Subtitle C of the Resource Conservation and Recovery Act.[251] The EPA concluded that states and the federal government were, for the most part, doing a reasonable job of controlling the impacts of these wastes.[252] Tellingly, the EPA highlighted the costs of regulatory compliance if the federal government were to treat the wastes as hazardous, concluding that, under high-end estimates, compliance could cost several billion dollars.[253] With 70,000 wells apparently in play, the average cost per well of such regulatory compliance might not have seemed so overwhelming[254]: $7 billion divided by 70,000 is $100,000. But, the EPA was apparently impressed. It ultimately exempted most oil and gas wastes from RCRA Subtitle C regulation,[255] thus ensuring that what was perceived as a potentially costly regulatory barrier would not impede well development.

As members of the oil and gas industry, unconventional gas producers also benefited from other exemptions during the developmental stages of the shale gas boom. For example, Congress did not hold operators liable for cleanup 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.[256]

In short, in the decades preceding the shale gas boom, producers looking to exploit shale gas and other unconventional reserves enjoyed regulatory exemptions that might have tipped cost–benefit analyses in favor of such activities. By analogy with the "infant industry" exception to arguments for free trade,[257] one can envision an "infant technology" argument for such

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[251] Regulatory Determination for Oil and Gas and Geothermal Exploration, Development and Production Rates, 53 Fed. Reg. 25,446, 25,447 (July 6, 1988). *See generally* James R. Cox, *Revisiting RCRA's Oilfield Waste Exemption as to Certain Hazardous Oilfield Exploration and Production Wastes*, 14 VILL. ENVTL. L.J. 1, 2–7 (2003) (providing a history of the exemption and explaining the exemption's scope).

[252] 53 Fed. Reg. at 25,446.

[253] *Id.* at 25,450.

[254] These numbers were based on an estimated "70,000 crude oil and natural gas wells" and additional wastes from geothermal energy wells. *Id.* at 25,448.

[255] 42 U.S.C. §§ 6921(b)(2)(A)–(B); 6982(m)(1) (2012); 53 Fed. Reg. 25,446.

[256] 42 U.S.C. § 9601 (14) (2012). Oil companies, though, still faced Clean Water Act liability and, as of 1990, Oil Pollution Act liability for onshore spills. 40 C.F.R. § 112.1 (1990).

[257] Marc J. Melitz, *When and How Should Infant Industries Be Protected?*, 66 J. INT'L ECON. 177, 178 (2005) ("The infant industry argument is one of the oldest arguments used to justify the protection of industries from international trade."); *see also* JOHN STUART MILL, PRINCIPLES OF POLITICAL ECONOMY 612 (J. Laurence

favorable regulatory treatment as a means to encourage a critical mass of early-stage activity when broad-scale commercial feasibility is still in doubt and the activity in question is economically marginal enough that it is at great risk of being snuffed out. Further, at least while activity levels are low in such a period of infancy, one might expect that the costs of regulatory exemptions will be relatively small and isolated.

But the broad-based regulatory exemptions for oil and gas activities described above have commonly applied to well-established as well as arguably "infant" activities and thus have not been tailored to fit an infant-technology rationale. Moreover, when more tailored regulatory relief was enacted, the period of infancy was past. Through the so-called "Halliburton Loophole,"[258] the Energy Policy Act of 2005 exempted all hydraulic fracturing, with the exception of fracturing that uses diesel fuel, from the definition of "underground injection" under the Safe Drinking Water Act.[259] 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. Although this exemption is well tailored to fit fracturing activities that proved critical to shale gas extraction, it came more than three years after Mitchell Energy merged with Devon Energy[260] and more than half a decade after a pronounced upward kink in Barnett Shale gas production from 1999 to 2000.[261] In short, when lawmakers ultimately provided regulatory relief tailored to the exploitation of shale gas reserves, they apparently did so at a time when they were no longer nurturing infant activity but instead feeding an already gathering boom.

Laughlin ed., New York, D. Appleton & Co. 1884) ("The only case in which, on mere principles of political economy, protecting duties can be defensible, is when they are imposed temporarily . . . in hopes of naturalizing a foreign industry, in itself perfectly suitable to the circumstances of the country.").

258 Warner & Shapiro, *supra* note 24, at 479–80.

259 42 U.S.C. § 300h(d)(1) (2012). 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. 33 U.S.C. § 1362(24) (2012). But the effectiveness of this exemption has been unclear. *See* Natural Res. Def. Council v. EPA, 526 F.3d 591, 594 (9th Cir. 2008) (curtailing EPA's efforts to implement the statutory exemption); *Regulation of Oil and Gas Construction Activities*, U.S. ENVTL. PROTECTION AGENCY (Mar. 9, 2009), http://water.epa.gov/polwaste/npdes/stormwater/Regulation-of-Oil-and-Gas-Construction-Activities.cfm (attempting to clarify relevant regulations).

260 STEWARD, *supra* note 106, at 179 ("In January 2002, the merger of Mitchell Energy and Devon closed . . . .").

261 *Id.* at 189 fig. 6-2 (showing relatively linear growth in Barnett Shale gas production from 1992 through 1999, followed by a pronounced upward kink in the growth trajectory from 1999 to 2000).

As the scope of drilling and fracturing activities has scaled upward, the wisdom of such late-coming regulatory relief has become subject to serious question.[262] More effective regulation might have limited now-evident social costs. There have been substantial spills and outflows of fracturing and drilling materials at well sites that have sometimes led to water contamination.[263] Moreover, disposal wells that accept liquid wastes from drilling and fracturing have been associated with earthquakes in several regions.[264] Drilling and fracturing also emit air pollution that can increase smog[265] and greenhouse gases.[266] Finally, although communities that have become hosts to booming natural gas production have experienced benefits,[267] they have also

[262] For a discussion of how scaling up activities can generate problems, see Hannah J. Wiseman, *Remedying Regulatory Diseconomies of Scale*, 94 B.U. L. REV. 235 (2014).

[263] *See, e.g.*, Wiseman, *supra* note 5, at 766–68, 799–801 (describing spills at well sites, including spills that entered swamps and other waters, based on state inspection reports); *Cases Where Pit Substances Contaminated New Mexico's Groundwater*, N.M. OIL CONSERVATION DIV. (Sept. 12, 2008), http://www.emnrd.state.nm.us/ocd/documents/GWImpactPublicRecordsSixColumns20081119.pdf (listing instances of groundwater contamination); Press Release, Md. Attorney Gen., AG Gansler Secures Funding to Safeguard Susquehanna Water Quality (June 14, 2012), *available at* http://www.oag.state.md.us/Press/2012/061412.html (reporting contamination by fracking fluids of farmland and a creek tributary).

[264] Frohlich et al., *supra* note 5; Austin Holland, *Oklahoma Geological Survey: Potential for Induced Seismicity Within Oklahoma*, GROUND WATER PROT. COUNCIL 6 (Jan. 23, 2013) http://www.gwpc.org/sites/default/files/event-sessions/Holland_AustinFINAL.pdf; Press Release, U.S. Geological Survey, Record Number of Oklahoma Tremors Raises Possibility of Damaging Earthquakes (May 2, 2014), *available at* http://earthquake.usgs.gov/contactus/golden/newsrelease_05022014.php (reporting that statistical analysis of "recent earthquake rate changes" in Oklahoma "suggests that a likely contributing factor . . . is triggering by wastewater injected into deep geologic formations"). Disposal wells are regulated under the Safe Drinking Water Act, but the Act does not cover induced seismicity. *See generally* UNDERGROUND INJECTION CONTROL NAT'L TECHNICAL WORKGRP., U.S. ENVTL. PROT. AGENCY, MINIMIZING AND MANAGING POTENTIAL IMPACTS OF INDUCED-SEISMICITY FROM CLASS II WELLS: PRACTICAL APPROACHES (2012), http://www.eenews.net/assets/2013/07/19/document_ew_01.pdf (studying the problem but not regulating it). Only Arkansas and Ohio have changed their regulations to fill the gap. OHIO ADMIN. CODE 1501:9-3-07 (2013); *Permanent Disposal Well Moratorium Area*, ARK. OIL & GAS COMM'N (June 7, 2011), http://www.aogc.state.ar.us/notices/Ex.%201B%20-Permanent%20Disposal%20Well%20Moratorium%20Area.pdf.

[265] *See* N.Y. DEP'T OF ENVTL. CONSERVATION, SUPPLEMENTAL ENVIRONMENTAL IMPACT STATEMENT 6-187 to 6-188 (2011), http://www.dec.ny.gov/data/dmn/rdsgeisfull0911.pdf (describing N_2O and carbon dioxide emissions from combustion at well sites); DALE WELLS, COLO. DEP'T OF PUB. HEALTH & ENV'T, CONDENSATE TANK EMISSIONS 2, 10 (2012), http://www.epa.gov/ttnchie1/conference/ei20/session6/dwells.pdf (showing that condensate tanks were the largest cause of regional nonattainment of air quality standards in the Denver area).

[266] Allen et al., *supra* note 58, at 17,769; Ramón A. Alvarez et al., *Greater Focus Needed on Methane Leakage from Natural Gas Infrastructure*, 109 PNAS 6435, 6438 (2012). EPA Clean Air Act regulations effective on January 1, 2015, will introduce partial regulation by requiring operators to capture certain emissions of volatile organic compounds (including methane). 40 C.F.R. § 60.5375 (2014).

[267] *Cf.* E.B., *Well-Being in America: Shale Gas Buys You Happiness*, ECONOMIST (Feb. 21, 2014, 5:59), http://www.economist.com/node/21597121 (suggesting that the shale gas boom is a large factor behind North

experienced a variety of costs. These include road damage and traffic, increased demand for physical infrastructure,[268] increased demand for city services such as fire and emergency response, rises in crime and drug use,[269] changes in historic economic activities like tourism and agriculture, and nuisances from the noise, light, dust, and pollution at well sites.[270]

In considering lessons from the story behind the fracking revolution, Part V examines how future policymakers might limit the downsides of regulatory relief as well as its possible tendency to persist and even expand after innovation-fostering justifications have substantially expired.[271] In the meantime, Part IV continues the discussion of factors behind the revolution itself by describing roles played by complementary assets, intellectual property rights, secrecy, and information sharing.

Dakota's rise to the top of the Gallup-Healthways Well-Being Index, meant to act as a measure of the mental and physical health of states' residents).

[268] *See, e.g.*, WILLISTON ECON. DEV., *supra* note 5, at 1 (noting that a prior increase in "major infrastructure capacity for up to 40% more population (pop 16,000)" had fallen short and there was additional need for "water, sewer, and road infrastructure for workforce housing and industry facility needs").

[269] A number of media sources report rising crime and drug use following fracking-related booms. *See, e.g.*, Jack Healy, *As Oil Floods Plains Towns, Crime Pours In*, N.Y. TIMES, Nov. 30, 2013, at A1, *available at* http://www.nytimes.com/2013/12/01/us/as-oil-floods-plains-towns-crime-pours-in.html; Michael Marks, *Drugs Follow Eagle Ford Energy Boom*, AUSTIN AM. STATESMAN (June 22, 2014), http://projects.statesman.com/news/eagle-ford-drugs/. Academic literature and government reports provide a more nuanced picture in which increases in crime might largely reflect population growth associated with such booms. *See, e.g.*, CAROL A. ARCHBOLD, "POLICING THE PATCH": AN EXAMINATION OF THE IMPACT OF THE OIL BOOM ON SMALL TOWN POLICING AND CRIME IN WESTERN NORTH DAKOTA 55 (2013), *available at* http://www.ndsu.edu/fileadmin/cjps/Policing_the_Patch_Report_-_Final_Draft_August_4th_-_Archbold.docx (noting that an apparent increase in crime was "proportionate with the increase in population"); Rick Ruddell et al., *Drilling Down: An Examination of the Boom-Crime Relationship in Resource-Based Boom Counties*, W. CRIMINOLOGY REV., Apr. 2014, at 3, 9 (finding "modest support for the proposition that crime is higher in oil producing counties and that crime increased after the Boom"); MONT. ALL THREAT INTELLIGENCE CTR. & N.D. STATE & LOCAL INTELLIGENCE CTR., IMPACT OF POPULATION GROWTH ON LAW ENFORCEMENT IN THE WILLISTON BASIN REGION 1 (2012), http://www.ag.nd.gov/reports/jointproductfinal.pdf ("With the increase in population there has been an increase in arrests, criminal activity and vehicle crashes.").

[270] WILLISTON ECON. DEV., *supra* note 5, at 26–28, 35; Susan Christopherson & Ned Rightor, *The Boom-Bust Cycle of Shale Gas Extraction Economies, Community & Regional Development Institute*, CARDI REP. (Cornell Univ. Cmty. & Reg'l Dev. Inst., Ithaca, N.Y.), Sept. 1, 2011, at 4, *available at* http://www.greenchoices.cornell.edu/downloads/development/shale/Economic_Consequences.pdf; Jeffrey Jacquet, *Energy Boomtowns & Natural Gas: Implications for Marcellus Shale Local Governments & Rural Communities* 14, 17, 22, 25, 28 (Ne. Reg'l Ctr. for Rural Dev., Paper No. 43, 2009), *available at* http://aese.psu.edu/nercrd/publications/rdp/rdp43; CJ Randall, *Hammer Down: A Guide to Protecting Local Roads Impacted by Shale Gas Drilling* 2 (Cornell Univ. Comprehensive Econ. Impact Analysis of Natural Gas Extraction in the Marcellus Shale Working Paper Series, 2010), *available at* http://www.greenchoices.cornell.edu/downloads/development/shale/Protecting_Local_Roads.pdf.

[271] *See infra* text accompanying notes 406–24.

IV. INTELLECTUAL PROPERTY, COMPLEMENTARY ASSETS, AND SHARING

A. Complementary Assets, Financing, 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.[272] The resulting lack of patent protection might have facilitated the subsequent shale gas boom, enabling others to rapidly copy Mitchell and Devon's techniques without having to pay licensing fees or worry about lawsuits for patent infringement.[273]

There is plausibility to the basic "no patent" story—really a "no patent" and "limited trade secret" story to the extent it suggests that significant 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 permanently secret, companies like Mitchell Energy and Devon Energy could use investments in complementary assets—private land and mineral rights—to appropriate substantial returns from innovation.[274]

Mitchell Energy 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 at a comparatively high price.[275]

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 too quickly drive up prices for rights to land and

272 Cahoy et al., *supra* note 26, 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.").

273 *Id.* at 291–92.

274 WANG & KRUPNICK, *supra* note 13, 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 from their early investments . . . .").

275 *See infra* text accompanying notes 276–78.

minerals in the Barnett Shale.[276] After Mitchell Energy had improved "its acreage position," it began working with GRI in the 1990s and ultimately made the key breakthroughs that it publicized in the early 2000s.[277] 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.[278]

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 environs.[279] "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."[280] 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 company was worth $8 billion.[281]

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"[282]—that underwrote the firms' capital investments and thus enabled a regime of information sharing with limited reliance on intellectual property.[283]

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276 *See* WANG & KRUPNICK, *supra* note 13, 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, 'concerned that any unnecessary publicity might adversely affect the growth of [the firm's] acreage position'" (alteration in original) (citation omitted)).

277 *Id.*

278 *See supra* text accompanying note 111.

279 Silver, *supra* note 13.

280 Cahoy et al., *supra* note 26, at 287 (quoting Silver, *supra* note 13).

281 Silver, *supra* note 13.

282 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").

283 *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").

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 as purchase efforts predictably drive up prices,[284] 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: rewards for the earliest movers left ample opportunities for others to profit from joining the game a bit later. 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 took on.

The naturally limited scope of private land and mineral leases as mechanisms for appropriation of value from innovation contrasts with the readily 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.

Another significant aspect of oil and gas leases is the developmental pressure that they can exert after being acquired. A typical oil and gas lease

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[284] *Cf.* John D. Sterman, *System Dynamics Modeling: Tools for Learning in a Complex World*, CAL. MGMT. REV., Summer 2001, at 8, 17 (discussing "self-limiting" processes featuring negative feedback such as how the relative attractiveness of a city generates increased "migration from surrounding areas . . . increasing unemployment, housing prices, crowding in the schools, and traffic congestion until the city is no more attractive than other places").

includes a clause stating that the lease has a "primary term" of a specified number of years and a secondary term that extends "as long thereafter as oil or gas is produced."[285] Once acquired, such a lease can provide a positive inducement to develop the acquired oil and gas resources before the end of the primary term in order to avoid losing the option to continue producing during the indefinitely long secondary term. Mitchell Energy itself appears to have responded to such inducement,[286] and it presumably was far from alone. As primary terms for leases appear commonly to be ten years or less,[287] the result of such lease arrangements could have been significant cumulative pressure to develop means of profitable exploitation within a quite limited span of time. The effects of such developmental pressure were not necessarily unambiguously positive, however. On the minus side, once commercial viability was established, the developmental spur of otherwise expiring lease rights might have contributed to excessive growth—from a social standpoint—of fracking and drilling activities by goading production activities forward even when more general social interests would have counseled restraint.[288]

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 did 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

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285 JOHN S. LOWE ET AL., CASES AND MATERIALS ON OIL AND GAS LAW 336 (5th ed. 2008).

286 STEWARD, *supra* note 106, at 124–25 (reporting management approval of various drilling operations in the wake of realization that various lease provisions could mean "that in the absence of drilling we would lose more than 5,000 acres").

287 LOWE ET AL., *supra* note 285, at 336 ("Ten years was once a common primary term, and it is still frequently the primary term of leases in unproven or marginally producing areas. Primary terms of from one to five years are more typical in states with established oil and gas production.").

288 *Cf.* Clifford Kraus & Eric Lipton, *After the Boom in Natural Gas*, N.Y. TIMES, Oct. 21, 2012, at BU1, *available at* http://www.nytimes.com/2012/10/21/business/energy-environment/in-a-natural-gas-glut-big-winners-and-losers.html (suggesting that natural gas companies are drilling and fracturing despite losing money overall).

increasing fossil fuel recovery.[289] Mitchell might have believed that, given this preexisting 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 broad enough to cover the particular fracturing techniques that other operators would find optimal for other formations. Indeed, there seems to be an impression among some commentators that, in the business of fossil fuel extraction, "few technologies are patentable."[290]

The posited assumption that patents were either unavailable or believed unavailable seems 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.[291] Moreover, Mitchell Energy, Devon Energy, and other players in the early stages of shale gas development did not lack sophistication that might be thought necessary to appreciate the potential availability of patent rights. "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."[292] Mitchell Energy was a sharp user of legal regimes in many respects[293] and was specifically familiar with the possibility of obtaining a patent for a novel variation on a previously developed technique: in the 1980s, Mitchell Energy 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.[294] Thus, it seems unlikely that Mitchell Energy refrained from patenting its improvements on previously developed

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289 *See* Michael Quentin Morton, *Unlocking the Earth: A Short History of Hydraulic Fracturing*, GEO EXPRO, Dec. 2013, at 86, 87, *available at* http://assets.geoexpro.com/uploads/31566c31-c43f-4cf1-8964-c1406108d667/GEO_ExPro_v10i6_Full.pdf ("From 1953, water was also used as a fracturing fluid, and various additives were tried to improve its performance.").

290 WANG & KRUPNICK, *supra* note 13, at 3; *see also id.* 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.").

291 *See infra* Part IV.C.

292 WANG & KRUPNICK, *supra* note 13, at 16–17.

293 *See supra* text accompanying notes 114, 195.

294 U.S. Patent No. 4,742,873 (filed Mar. 11, 1987) (issued May 10, 1988) (listing Mitchell Energy Corp. of The Woodlands, Texas, as the assignee); U.S. Patent No. 4,291,765 (filed Aug. 2 1979) (issued Sept. 29, 1981) (listing Mitchell Energy Corp. of Houston, Texas, as the assignee).

techniques of hydraulic fracturing as a result of straightforward mistakes about patent rights' potential availability.

Was Mitchell Energy motivated by philanthropic goodwill? In a 2012 interview, George Mitchell indicated that he believed Mitchell or Devon "could have patented [their] proprietary process and made exponentially more money" but that he "already had enough money from the sale of Mitchell Energy & Development Corp. to Devon Energy," and he "was more motivated to introduce this technology into the public domain—make it public record—so that the world could benefit from natural gas as an important energy and fuel source."[295] George Mitchell might well have believed this, but Mitchell Energy's commitment to not pursuing patent protection appears to have preceded the large payday with Devon. The key technical breakthroughs were made by the end of 1998,[296] and those breakthroughs were apparently used to generate natural gas for sale essentially immediately.[297] This commercial exploitation presumably barred Mitchell Energy from seeking related patents at any time more than a year after its occurrence[298]—substantially before the 2002 sale to Devon.

A better explanation for the non-pursuit of patent protection might be that Mitchell Energy simply believed that, as a matter of pure private interest, pursuing patent rights was not worth the trouble. This conclusion might have followed from a combination of (1) difficulties in enforcing patent rights on processes of extraction commonly conducted in relatively isolated locations, out of plain sight, or even deep underground;[299] (2) the potential value of keeping certain aspects of Mitchell's advances secret, as opposed to disclosed in issued patents or published patent applications;[300] (3) open-access

[295] S.W., *An Interview with George Mitchell: The Industry Can No Longer Simply Focus on the Benefits of Shale Gas*, ECONOMIST, Aug. 1, 2013, http://www.economist.com/blogs/schumpeter/2013/08/interview-george-mitchell.

[296] *See supra* note 106 and accompanying text.

[297] *See* STEWARD, *supra* note 106, at 123 ("Mitchell's expansion phase of the Barnett began in 1998 and continued through the end of 2001.").

[298] *See* JANICE M. MUELLER, AN INTRODUCTION TO PATENT LAW 141 (2d ed. 2006) (discussing how, even if an invention's use is kept secret, a time-based statutory bar to patenting can prevent patenting of the invention at any time more than one year after the invention's "secret commercialization").

[299] *Cf.* Golden, *supra* note 9, at 518 ("[D]ifficulties in enforcing patent rights might . . . cause rational parties either not to obtain patent rights at all or, alternatively, to leave such rights unenforced or licensed for only pennies on the dollar." (footnote omitted)).

[300] *See id.* at 521–22 (noting surveys indicating that private firms commonly view patent disclosures as "cost[s] to the patentee"). U.S. applications filed before November 29, 2000, were not subject to a requirement

requirements resulting, for example, from Mitchell's collaboration with GRI;[301] and (4) developed industry norms of competition based on an accepted mix of partial disclosure, partial secrecy, and localized exclusive rights in land and minerals—norms that might have successfully fostered an environment in which relevant players could appropriate a satisfactory amount of value from their own technological advances but at the same time benefit generally from advances made by others.[302]

These potential factors in Mitchell's non-pursuit of patent rights merit additional discussion. First, there is the fact that, at least from an ex ante perspective, a producer like Mitchell might very likely have viewed patents on processes of fracturing or directional drilling as unlikely to have great value. Mitchell was looking to generate a commodity—salable natural gas. Generally speaking, innovations in hydraulic fracturing such as a new technique of slickwater fracturing—the sorts of innovation that an independent producer like Mitchell would most likely generate—would not be visible in publicly sold end products. Instead, such a new technique would likely appear in practice only ephemerally in privately deployed processes to extract natural gas whose most directly relevant aspects could occur a mile or so underground.[303] Detection and proof of the infringement of a patent on such a technique might be difficult.[304] Further, the patented technique might have only localized and thus significantly limited value: its advantages might be limited to the specific kinds of geologic conditions for which it was originally

that they be published if still pending after eighteen months, but Mitchell Energy could have applied for applications abroad, where a practice of publishing patent applications after eighteen months would likely have applied. *See* ROBERT PATRICK MERGES & JOHN FITZGERALD DUFFY, PATENT LAW AND POLICY: CASES AND MATERIALS 61 (5th ed. 2011) ("By the mid-1990's, the United States was one of the last holdouts of secret applications in the world.").

301 *See supra* text accompanying notes 195–98.

302 *Cf.* Lior Jacob Strahilevitz, *Social Norms from Close-Knit Groups to Loose-Knit Groups*, 70 U. CHI. L. REV. 359, 359–60 (2003) (arguing for extension of the study of the development and maintenance of social norms of cooperation to "non-close-knit groups").

303 *See supra* text accompanying note 78.

304 *See, e.g.*, Rebecca S. Eisenberg, *Technology Transfer and the Genome Project: Problems with Patenting Research Tools*, 5 RISK 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"); 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 problems proving infringement.").

developed.[305] Under such circumstances, the expected costs of obtaining and enforcing patent rights could well have outweighed the expected benefits.

The cost of patent-law-mandated disclosure seems likely to have been one that Mitchell Energy would have considered. Mitchell separately demonstrated its appreciation of the desirability of keeping certain information secret. Recall how Mitchell deliberately sought to delay information flow about its knowledge and activities so as not to interfere with its plans for profitable acquisition of land and mineral rights.[306]

Further, Mitchell had worked with GRI and might therefore have been at least partially subject to GRI-imposed restrictions on intellectual property.[307] Even if such restrictions only partly limited the extent to which Mitchell could seek or enforce rights in particular techniques of well drilling or development, such limitations could help cap the expected value of any patent rights or, at the very least, highlight what GRI-imposed restrictions required to remain uncovered.

More generally, however, Mitchell Energy might simply have followed a mixed strategy of partial secrecy, acquisition of local exclusionary rights in land and minerals, and partial disclosure that generally served its interests and was also well within the established norms—the laws of economic warfare—for its industrial context. In this context, private parties such as Mitchell had substantial interests in at least partially free information exchange. Mitchell appreciated that the sharing of information could serve its strategic interests. In the mid-1990s, "management recommended that [Mitchell] begin sharing data with other operators in hopes of increasing competitor activity to evaluate wildcat areas."[308] Later, a "Barnett Shale Symposium" on September 28, 2000, that featured "a variety of excellent technical presentations" helped stoke interest in the Barnett play to Mitchell's apparent benefit.[309]

Further, presumably like many independents with limited research budgets, Mitchell Energy actively sought valuable information from others, both through direct talks and through hiring. Mitchell pursued the technique of

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305 *See supra* notes 78–80 and accompanying text.

306 *See supra* text accompanying notes 275–78.

307 *See infra* text accompanying notes 313, 319.

308 STEWARD, *supra* note 106, at 175–76.

309 *Id.* at 178–79 ("Following the symposium Mitchell Energy received numerous inquiries about the play. Soon afterwards Devon approached Mitchell concerning a merger.").

slickwater fracturing in shale only after the Mitchell engineer "assigned completion responsibility for the Barnett," Nick Steinsberger, followed experimentation with the use of a low concentration of gel with outreach to representatives of Union Pacific Corporation.[310] Union Pacific had developed a slickwater technique for fracturing "in low permeability rock," and "Nick obtained approval . . . to discuss their frac[turing] design and its possible application to the Barnett Shale."[311] Shortly before Mitchell's 1998 breakthrough, Mitchell also benefited from Chevron's abandoned efforts in the Barnett Shale by hiring "Kent Bowker, a highly-experienced, unconventional-gas geologist from Chevron," whom Mitchell valued not only for his innate talent but also for "his knowledge of Chevron's Barnett science."[312]

Government actors or partners might have contributed to a culture and strategic calculus of information exchange. Partnerships such as those Mitchell Energy had with GRI apparently triggered requirements of "full publication of findings" and surrender of claims to intellectual property.[313] As noted earlier,[314] FERC, for its part, helped ensure that GRI "focused on technology diffusion," rather than developing revenue from intellectual property, by "subtracting any royalties [from intellectual property] from FERC funding."[315] The plausibility of FERC and GRI thereby influencing the more general industry culture might find support in the history of the largely contemporaneous "Bayh-Dole model" for university research that encouraged universities to seek patents on the results of federally funded research and then to use these patents as levers for commercialization.[316] Whether the Bayh-Dole

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310 *Id.* at 112–13.

311 *Id.* at 113 ("In the fall of 1996 [Nick, a Mitchell Energy representative,] met with Mike Meyerhoffer and his supervisor Ray Walker, and reviewed their well and frac data. Nick was extremely encouraged about the techniques' potential in the Barnett.").

312 *Id.* at 122–23; *see also id.* at 129 ("Kent Bowker joined Mitchell Energy in February 1998, and was given geological responsibility for the Barnett play.").

313 BURWEN & FLEGAL, *supra* note 50, at 5.

314 *See supra* text accompanying notes 193–94.

315 BURWEN & FLEGAL, *supra* note 50, at 5.

316 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 such technology transfer by allowing government grantees and contractors to patent inventions and to sell exclusive licenses for their use.").

model has proven optimal is controversial,[317] but there can be little doubt that government endorsement of this approach helped foster an environment in which universities took increasingly proprietary and exclusionary views of the fruits of their intellectual efforts.[318] GRI's quite distinct, partly opposite approach might predictably have nudged private actors in an alternative direction.

In any event, information-sharing requirements and cultural norms fostered by GRI were not the only government supports for information sharing. Under regulations applicable in most of North America, oil and gas producers had to "reveal fracturing and production-performance data within 6 months."[319] 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."[320] 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 suggested by Mitchell's story,[321] as long as a producer 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 by attracting copycats who would drive up the value of the early mover's land and mineral rights by seeking to buy their way into a winning play.

Moreover, energy companies might have partly embraced information sharing 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 include multinational firms such as Halliburton Co. and Schlumberger Ltd.,[322] acted as natural cross-pollinators

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

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

319 Montgomery & Smith, *supra* note 62, at 36.

320 *Id.*

321 *See supra* text accompanying notes 275–78.

322 *See Corporate Profile*, HALLIBURTON, http://www.halliburton.com/en-US/about-us/corporate-profile/default.page?node-id=hgeyxt5p (last visited Mar. 5, 2015); *Multistage Fracturing Services*, SCHLUMBERGER, http://www.slb.com/services/completions/stimulation/reservoir/contact.aspx (last visited Mar. 5, 2015).

of techniques and geological information as they moved from job to job and company to company, making tight restriction of certain transfers of knowledge likely to be difficult, if not practically impossible.[323]

In short, general difficulties with policing infringement of process-patent violations might have combined with the overall regulatory environment, government policies, industry norms, difficulties with restricting information flow and enforcing patent rights, and the viability of a mixed strategy of secrecy and disclosure to make pursuit of patenting undesirable to individual players. At a group level, failure to seek or enforce patent rights and willingness to share certain kinds of information might have enabled a regime of relatively open access to new techniques and knowledge, an environment in which a great number of variegated players had an opportunity to benefit.[324]

C. Secrecy and Non-Kitchian Patents

Nonetheless, despite a substantial amount of information sharing within the oil and gas industry, characterization of the fracking revolution's relevant technology space as an "IP-free" or "negative IP" zone[325] 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 secret. Further, patents on aspects of hydraulic fracturing, directional drilling, or associated technologies have long been a feature of various lines of innovation that converged to foster 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

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[323] NAT'L RESEARCH COUNCIL, *supra* note 34, 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."); *see also* Hinton, *supra* note 6, at 234–35 (observing that, although George Mitchell "tried to keep his remarkable success [in the Barnett Shale] under wraps to pick up more leases," other independents obtained "information passed along the well-service-contractor grapevine" and "began leasing in areas adjoining Mitchell Energy's leased land").

[324] *See* 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").

[325] *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").

flow and difficulties in controlling that flow are often emphasized.[326] On the other hand, as indicated above in discussing companies' hybrid strategies of disclosure and nondisclosure,[327] it is clear that not all information is shared. 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."[328] 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.[329] Perhaps even more tellingly, firms involved in hydraulic fracturing have long fought against requirements that they disclose details of the chemical composition of fracking fluids on grounds that these details are commercially valuable trade secrets.[330] Whether the anticipated "regulatory cost" of disclosure to the public, as opposed to the anticipated "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 substantial residuum of information that individual players seek to hold as their own.

Secrecy is not the only way by which companies have sought 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.[331] Regardless of whether this is true, patents

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326 *See supra* notes 299–302 and accompanying text.

327 *See supra* text accompanying notes 308–18.

328 BURWEN & FLEGAL, *supra* note 50, at 5.

329 *See, e.g.*, Grynberg v. Total S.A., 538 F.3d 1336, 1342 (10th Cir. 2008) (noting a consortium agreement among energy companies with a primary purpose to "implement an 'exploration research study' to obtain and interpret seismic and other geologic data").

330 *See supra* note 24 and accompanying text.

331 Cahoy et al., *supra* note 26, 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 290–91 ("[F]racturing fluids are the apparent reason for the increase in patent activity in the gas extraction industry.").

have essentially always been present with respect to key technologies that undergird the shale gas boom.

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.[332] 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.[333] Soon after these patents issued, Stanolind licensed them to a service company, Halliburton Oil Well Cementing Co.[334] 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 non-exclusivity by receiving one third of royalties received under Stanolind's licenses with others.[335]

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,[336] the Dow Chemical Co.,[337] Esso Production Research Co.,[338] Mobil Oil Corp.,[339] Pan American Petroleum

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[332] Montgomery & Smith, *supra* note 62, at 27.

[333] *E.g.*, Well Completion Process, U.S. Patent No. 2,667,224 (filed June 29, 1949) (issued Jan. 26, 1954); Treatment of Wells, U.S. Patent No. 2,596,845 (filed May 28, 1948) (issued May 13, 1952); Treatment of Wells, U.S. Patent No. 2,596,844 (filed Dec. 31, 1949) (issued May 13, 1952); Fracturing Formations in Wells, U.S. Patent No. 2,596,843 (filed Dec. 31, 1949) (issued May 13, 1952) (reissued as U.S. Patent Re. 23,733 on Nov. 10, 1953).

[334] Montgomery & Smith, *supra* note 62, at 27.

[335] Cahoy et al., *supra* note 26, at 289.

[336] U.S. Patent No. 5,054,554 col. 1 ll. 41–46 (filed July 13, 1990) ("[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.").

[337] U.S. Patent No. 3,302,717 col. 8 ll. 11–13 (filed Dec. 26, 1961) (claiming a "method of fracturing a well penetrating a subterranean formation"); U.S. Patent No. 3,181,612 col. 9 ll. 49–51 (filed July 7, 1961) (claiming the same).

[338] U.S. Patent No. 3,378,074 col. 1 ll. 26–28 (filed May 25, 1967) ("This invention relates to the hydraulic fracturing of subterranean formations surrounding oil wells, gas wells and similar boreholes.").

[339] U.S. Patent No. 4,892,147 col. 4 ll. 44–45 (filed Dec. 28, 1987) (claiming a "method for hydraulically fracturing a formation where a fused refractory proppant is used"); U.S. Patent No. 3,858,658 col. 5 ll. 58–60 (filed Nov. 19, 1973) (claiming a "method of forming a vertical fracture in a thick subterranean formation").

Corp.,[340] and Standard Oil Development Co.[341] Some patents relating to hydraulic fracturing issued to less prominent assignees, including individual inventors[342] or companies such as California Research Corp.[343] and Intercomp Resource Development and Engineering, Inc.[344]

The multiple technological aspects of fracking processes offered ample opportunities for associated sub-innovations. Almost immediately, patents issued on mere parts of hydraulic fracturing processes or on materials and devices associated with such processes. As early as 1951, Sinclair Oil obtained a patent on a "process for breaking soap thickened petroleum gels"[345] used in fracturing, the point being that breaking down the gels would enable readier removal of fracking fluid from a formation.[346] In 1952, Stanolind obtained a patent on "an improved composition of matter," "an oil-in-water emulsion which is particularly adapted to be used in the Hydrafrac process."[347] In the decades leading up to Mitchell's late 1990s breakthrough, companies and individuals obtained additional patents that involved a variety of fracking-related details, devices, components, or sub-techniques: for example,

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340 U.S. Patent No. 2,986,213 col. 4 ll. 5–8 (filed Aug. 12, 1957) (claiming a process "wherein quantities of a hydrocarbon liquid and blackstrap molasses are alternately injected into said well at a rate sufficient to extend a fracture into said formation"); U.S. Patent No. 2,838,117 col. 1 ll. 17–19 (filed May 22, 1953) (describing "an improvement in hydraulic fracturing processes wherein the fractures may be produced at selected elevations").

341 U.S. Patent No. 2,547,778 col. 1 ll. 1–5 (filed July 5, 1949) ("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.").

342 *E.g.*, U.S. Patent No. 2,927,638 col. 1 ll. 15–16 (filed Jan. 10, 1955) ("This invention relates to improvements in the fracturing of the earth formation surrounding wells . . . ."); U.S. Patent No. 2,915,122 col. 1 ll. 18–20 (filed Jan. 16, 1956) ("This invention particularly relates to an improved method for hydraulically fracturing . . . underground formations . . . .").

343 U.S. Patent No. 2,859,821 col. 5 ll. 26–28 (filed Sept. 8, 1953) (claiming a "method for increasing the productivity of a subterranean formation penetrated by a well by hydraulic fracturing").

344 U.S. Patent No. 3,933,205 col. 1 ll. 21–25 (filed Jan. 27, 1975) ("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 . . . .").

345 U.S. Patent No. 2,652,370 col. 4 ll. 20–22 (filed Apr. 20, 1951).

346 *Id.* col. 4 ll. 15–18.

347 U.S. Patent No. 2,742,426 col. 1 ll. 11–15 (filed July 28, 1952).

specific forms of proppants,[348] gels,[349] "gel breakers,"[350] fracking-fluid mixtures,[351] approaches to generating holes in well casings through which fracking fluid can exert pressure on surrounding rock,[352] methods for seismic imaging of induced fractures,[353] and "measurement of delayed gamma rays" to determine the distribution of proppant within a formation.[354]

Patents similarly chronicle decades of technological developments that culminated in modern directional drilling. At least since the early 1920s, there were patent claims relating to deflected drilling using a whipstock[355] and even for a technique of drilling a horizontal hole using a guide pipe with a vertical-to-horizontal elbow.[356] By the 1980s, there was a drumbeat of issued

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348 U.S. Patent No. 4,892,147 col. 2 ll. 5–7 (filed Dec. 28, 1987) ("This invention relates to a method for hydraulic fracturing a formation where a fused refractory proppant is utilized."); U.S. Patent No. 3,888,311 col. 1 ll. 50–55 (filed Oct. 1, 1973) ("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. Patent No. 3,708,560 col. 2 ll. 12–21 (filed July 12, 1971) (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").

349 U.S. Patent No. 4,779,680 col. 2 ll. 11–13 (filed May 13, 1987) ("The gel employed in the fracturing process of the present invention comprises a polymer, an aqueous solvent, and a crosslinking agent."); U.S. Patent No. 3,727,689 col. 2 ll. 6–10 (filed Feb. 9, 1972) ("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.").

350 U.S. Patent No. 3,163,219 col. 1 ll. 10–12 (filed June 22, 1961) ("[T]his invention concerns delayed action gel breakers for borate-gum gels."); U.S. Patent No. 2,774,740 col. 5 ll. 8–14 (filed Feb. 12, 1954) (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").

351 U.S. Patent No. 2,793,998 col. 1 ll. 14–17 (filed Feb. 28, 1956) ("[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.").

352 U.S. Patent No. 5,564,499 col. 1 ll. 7–10 (filed Apr. 7, 1995) ("This invention relates to a method and apparatus for penetrating well casings and scoring the surrounding rock to facilitate hydraulic fractures.").

353 U.S. Patent No. 3,739,871 col. 1 ll. 6–11 (filed July 30, 1971) (describing an invention "in the field of seismic mapping" "concerned with the problem of determining the position . . . of the fractures which are induced . . . by the application of high fluid pressures to the rock wall of the bore hole").

354 U.S. Patent No. 4,926,940 col. 2 ll. 19–27 (filed Sept. 6, 1988).

355 U.S. Patent No. 2,586,662 col. 1 ll. 3–7 (filed Aug. 20, 1948) ("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. Patent No. 1,970,761 col. 1 ll. 1–3 (filed Oct. 3, 1932) ("This invention relates to the use of a whipstock whereby a bit is deflected from a course which it has previously pursued."); U.S. Patent No. 1,454,048 col. 1 ll. 10–28 (filed Sept. 29, 1921) (describing "an improvement in the process known, in the art of drilling oil wells, as 'side tracking'").

356 U.S. Patent No. 1,367,042 col. 1 ll. 80–82 (filed Dec. 8, 1919) (describing how "an elbow" is attached to the end of a set of "rigid pipe sections").

patents relating to directional drilling with downhole motors[357] or to new approaches to monitoring drilling progress.[358] Initial assignees for these patents included service companies or suppliers for the oil and gas industry such as Halliburton Co.,[359] Maurer Engineering Inc.,[360] and Schlumberger Technology Corp.,[361] but patent rights assigned to major producers were not unknown.[362]

In sum, far from being patent free, various lines of innovation that converged to generate the technologies behind the fracking revolution 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."[363]

Nonetheless, despite their availability and actual presence, patents appear not to have played a major role in either stimulating or impeding the final breakthroughs that opened U.S. shale formations to commercial exploitation on a grand scale.[364] 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

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357 *See, e.g.*, U.S. Patent No. 4,811,798 col. 1 ll. 4–7 (filed Oct. 30, 1986) ("This invention pertains to the use of down hole well drilling motors . . . to accomplish either straight hole drilling or directional drilling . . . ."); U.S. Patent No. 4,492,276 col. 1 ll. 6–9 (filed Oct. 13, 1983) ("The invention relates to a down-hole drilling motor and a method for directional drilling by means of said motor . . . ."); U.S. Patent No. 4,185,704 col. 1 ll. 58–61 (filed May 3, 1978) (describing "new and useful improvements in apparatus for directional drilling" that are "particularly adapted to the use of in-hole drilling motors").

358 *See, e.g.*, U.S. Patent No. 5,160,925 col. 1 ll. 6–37 (filed Apr. 17, 1991) (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. Patent No. 5,139,094 col. 1 ll. 6–11 (filed Feb. 1, 1991) ("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 . . . .").

359 U.S. Patent No. 5,332,048 (filed Oct. 23, 1992) (listing Halliburton as the assignee); U.S. Patent No. 5,086,850 (filed Apr. 2, 1991) (same).

360 U.S. Patent No. 4,991,668 (filed Feb. 6, 1989) (listing Maurer Engineering Inc. as the assignee); U.S. Patent No. 4,185,704 (filed May 3, 1978) (same).

361 U.S. Patent No. 5,311,952 (filed May 22, 1992) (listing Schlumberger Technology Corp. as the assignee).

362 *See* U.S. Patent No. 4,492,276 (filed Oct. 13, 1983) (listing Shell Oil Co. as the assignee).

363 Kyungpo Lee & Sungjoo Lee, *Patterns of Technological Innovation and Evolution in the Energy Sector: A Patent-Based Approach*, 59 ENERGY POL'Y 415, 415–16 (2013).

364 *See supra* Part I.

launching the field or in coordinating subsequent activity.[365] Instead, the federal government and its non-patent-oriented beneficiary, GRI, played vital coordinating roles for an industry featuring a multitude of independent producers,[366] and the prospect of vastly increased prices for complementary assets—land and mineral rights—provided these private actors with their the dominant stimulus.[367] Consistent with Robert Merges and Richard Nelson's general competition-based prescription for technological progress,[368] the competitiveness and relative nimbleness of independent gas producers—not broad, early-stage patent rights—drove rapid diffusion and adaptation of Mitchell Energy's key breakthroughs to a multitude of widely dispersed drilling sites.[369]

Relative to the explosion of innovation that non-patent factors spurred, patents played a quieter background role. Patents might well have helped foster a slow, decades-long drip of incremental innovation, a drip that gradually built up vast reservoirs of relevant technological capacity and know-how.[370] 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 for the fracking revolution that, although not a truly "no patent" story, is still a tale that limits patents to a relatively humble role. The story is also something of a counterexample—or exception—to theories that patents are particularly crucial to fostering disruptive, breakthrough innovation.[371] In the story of the fracking

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365 *See* Kitch, *supra* note 25, 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").

366 *See supra* Part III.A.

367 *See supra* Part IV.A.

368 *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.").

369 *See* Montgomery & Smith, *supra* note 62, 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.").

370 *Cf.* John M. Golden, *Litigation in the Middle: The Context of Patent-Infringement Injunctions*, 92 TEX. L. REV. 2075, 2115 (2014) (suggesting that, in practice, the patent system's focus might be "directed not so much at awe-inspiring forward strides but instead at more innocuous advances and the quiet, comparatively diffuse cumulation of social betterment").

371 *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" (footnote omitted)).

revolution, the ready availability of complementary assets that could richly reward innovation—analogs of the very mineral rights that helped inspire Edmund Kitch's "prospect theory" for patents[372]—might explain why, in this case, patents appear to have been relegated to such an unheroic, non-Kitchian role.

V. LEARNING FROM THE CASE STUDY

The technological revolution behind the early twenty-first century's shale gas boom provides a great story of success in innovation. Decades of technological advances and developments in policy and infrastructure converged to open vast new reserves of energy that offer the possibility of substantial economic, political, and even environmental benefits.[373]

But this story of success is also a story of human limitation and failure. Indeed, Mitchell's persistence in the face of more than a decade of relative failure is part of what makes the ultimate success of the fracking revolution so compelling.[374] More broadly, the story behind the fracking revolution is intriguing partly because it is far from a story of streamlined technological advance. Key innovations took decades to emerge, relied on a multitude of overlapping and frequently only loosely tailored governmental and private initiatives, and culminated in an oil and gas boom that arguably overreached, squandering at least some of the technological revolution's positive potential.[375]

There are lessons for innovation policy and theory in this story of success and failure. Although one fundamental lesson involves innovation's sensitivity to context, a number of additional lessons have the capacity to be relevant across a wide range of circumstances. Part V.A discusses such lessons, and Part V.B explores how at least some of those lessons might inform attempts to foster similar technological revolutions in renewable energies or in the extraction of oil and gas outside the United States.

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[372] *See* Kitch, *supra* note 25, at 271–75 (comparing aspects of the United States' "mineral claim system" and the patent system).
[373] *See supra* text accompanying notes 51–60.
[374] *Cf. supra* text accompanying note 13.
[375] *See supra* text accompanying notes 206–14.

A. *Lessons for Innovation Policy and Theory*

Because federal and state governments implemented a smorgasbord of innovation-related policies such as 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 general, universal truths about how a wealth of apparent policy levers can be best used to promote innovation. But this Article's case study does suggest some context-sensitive lessons about the circumstances and policies that can nurture breakthrough innovations like those behind the fracking revolution. In particular, this case study suggests five categories of lessons for later policymakers: (1) the potential need for great patience in fostering transformative technological change; (2) the potential importance to the same end of a diverse innovation ecosystem; (3) the crucial roles that governments and infrastructure can play even when private initiative is central; (4) the possibility of achieving a productive balance of public and private interests through mixed information strategies with both sharing and proprietary aspects; and (5) the predictable need for policy adjustment as a technology spreads and matures.

1. *Patience and Stable Reward Mechanisms*

As indicated above, the story of the fracking revolution is far from streamlined and compact. 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."[376] Stanolind Oil & Gas pioneered hydraulic fracturing a half century before Mitchell Energy's critical 1998 breakthrough,[377] and directional drilling with downhole motors had been maturing since the 1980s.[378] The Eastern Gas Shales Project launched in 1976,[379] and during the intervening decades, shale gas development had enjoyed consistent support from a combination of DOE and GRI funding as well as various forms of tax and regulatory relief.[380] Meanwhile, an infrastructure of pipelines and markets for natural gas that could reward

376 BURWEN & FLEGAL, *supra* note 50, at 2.
377 *See supra* text accompanying note 68.
378 *See supra* text accompanying notes 87–94.
379 *See supra* text accompanying note 166.
380 *See supra* Part III.

exploitation of unconventional reserves continued to develop.[381] Despite all this, Mitchell's 1998 success came as something of a surprise, and it took additional years for markets to appreciate its implications.[382]

The long and unpredictable gestation of the fracking revolution highlights that policymakers might need to exercise substantial patience in fostering transformative technological breakthroughs. Perhaps more to the institutional-design point, this potential need for patience suggests that innovation–reward mechanisms possessing substantial reliability over time can be crucial to fostering game-changing innovations. In this respect, Mitchell might have been particularly fortunate in being able to appropriate at least a substantial portion of the value of innovation through well-established complementary assets, land and mineral leases,[383] that were relatively unlikely to be rolled back with the whims of political cycles. The availability of stable and relatively apolitical mechanisms for rewarding success might be particularly crucial when success is likely to be long in coming.

2. *A Diverse Innovation Ecosystem*

A second point relates to the value of diversity, diversification, and decentralization in innovation ecosystems.[384] The federal government's investment in unconventional natural gas—a field largely neglected by major producers[385]—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. The United States' possession of a throng of experienced independent producers and service companies, perhaps in part a product of a system of decentralized private property rights in land and minerals,[386] helped avoid a situation in which the major producers' neglect would have required governments to try to develop from scratch the

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381 *See supra* Part II.

382 *See supra* text accompanying notes 13, 110–12.

383 *See supra* text accompanying notes 276, 279.

384 *See generally* Merrill, *supra* note 109, at 980 (identifying "decentralization of control over resource development" as the key reason "the United States developed fracking technology before anyone else").

385 *See supra* note 177 and accompanying text.

386 *Cf.* Merrill, *supra* note 109, at 978–80 (linking private ownership of mineral rights in the United States to "decentralization of control" and openness to experimentation with extraction techniques).

institutional means for shale gas development. State and federal governments did not need to invent a Mitchell Energy. Instead, they could succeed by providing more marginal inducements and support for private entities ready to take a swing at making shale gas commercially viable.

The crucial role of independents in the fracking revolution should not completely overshadow the important role played by major producers and prominent service companies in helping to develop much of the technology and knowledge that independents such as Mitchell deployed. Records of U.S. patents attest to multiple streams of innovation stretching over decades to which large companies contributed,[387] and Mitchell Energy's own eager pursuit of information and know-how developed by Chevron suggests the value that even abortive or tangential efforts by well-resourced majors could add.[388] In short, the story of the fracking revolution indicates the potential value of an innovation ecosystem that supports a diverse range of business models and retains openness to contributions to innovation from any quarter.[389] The value of a diverse innovation ecosystem bears some relation to the value of biological diversity: just as biological diversity can make a species or ecosystem more robust and adaptable to new circumstances,[390] diversity in enterprise forms can render an economic system hardier and nimbler in exploiting new opportunities. The fracking revolution seems a case in point.[391]

3. Government and Infrastructure

Part of the value of a diverse innovation ecosystem is its capacity to draw on the efforts of a great variety of private actors in helping to effect technological change. But the story of the fracking revolution also illustrates how government can play crucial roles in fostering and maintaining such an ecosystem. As comparisons with other nations make clear, even the private

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387 *See supra* text accompanying notes 336–62.

388 *See supra* text accompanying notes 311–12.

389 *Cf.* Hinton, *supra* note 6, at 230 ("[T]he connection between small and large industry players is often as much cooperative as it is competitive.").

390 *See* EDWARD O. WILSON, THE DIVERSITY OF LIFE 309 (rev. ed. 1999) ("In short, an ecosystem kept productive by multiple species is an ecosystem less likely to fail."); John Harte, *Land Use, Biodiversity, and Ecosystem Integrity: The Challenge of Preserving Earth's Life Support System*, 27 ECOLOGY L.Q. 929, 934 (2001) (contending that, to ensure the survival of salmon of the Pacific Northwest, "we must protect the diverse gene pool today so that adaptation is possible tomorrow").

391 *Cf.* Hinton, *supra* note 6, at 229–30 ("With their smaller scale operations, [independent producers] can look for oil in quantities too small too interest major companies and can make a profit on modest discoveries.").

property rights in land and mineral rights that played a central role in the fracking revolution reflect government policies and backing.[392] Further, either directly or through publicly sponsored entities such as the Gas Research Institute, governmental entities provided funding, engaged in cooperative public–private projects, helped coordinate private efforts, and encouraged information exchange.[393] Government raised the expected value of investments in unconventional resources through indirect subsidies such as tax benefits and regulatory exemptions.[394] Finally, the federal government in particular took a variety of steps that helped generate a robust interstate network of open-access pipelines and a natural gas market, crucial pieces of infrastructure for producers looking to develop more commercially marginal reserves.[395] This blend of government contributions was particularly vital for unconventional natural gas, a field dominated by independent producers that tended to lack the comparatively generous research and development budgets characteristic of the majors.[396]

4. Mixed Information Strategies and Non-Kitchian Patents

In suggesting the desirability of a diverse ecosystem of parties positioned to contribute to innovation, the story of the fracking revolution and ensuing boom also suggests the desirability of a diverse set of policy levers to sustain such an ecosystem and enable adaptation of policies over time. Further, the complicated and unpredictable nature of technological advance in the story indicates that significant technological developments might not always fit a Kitchian model, in which broad, early-stage prospect patents foster coordinated and relatively streamlined follow-on research.[397]

In the case of the fracking revolution, lightly coordinated development through DOE intervention and GRI leadership combined with largely patent-free exploration of technological possibilities to help generate the

392 *See infra* Part V.B.

393 *See supra* Part III.A.

394 *See supra* Parts III.B–C.

395 *See supra* Part II.

396 MIT STUDY, *supra* note 175, app.8A, at 1; *see also* Merrill, *supra* note 384, at 977 ("Mitchell had nothing comparable to the resources or the engineering talent of the major oil companies.").

397 *See supra* Part IV.C; *see also* Kitch, *supra* note 25, at 276 (discussing how "a patent 'prospect'" "puts the patent owner in a position to coordinate the search for technological and market enhancement of the patent's value so that duplicative investments are not made"); *id.* at 278 ("[A] patent system enables firms to signal each other, thus reducing the amount of duplicative investment in innovation.").

Mitchell synthesis and its stunningly rapid diffusion.[398] In conformity with Robert Merges and Richard Nelson's accounts of broad, early-stage patents that appear to have slowed later innovation,[399] the story of the United States' fracking revolution thus stands as an example of a situation in which restraint in patenting might have facilitated technological development, although patents might still have played a nontrivial, positive role by stimulating the generation and public disclosure of a continual trickle of innovations that ultimately provided fodder for the Mitchell synthesis.[400] The leaky, plural, even chaotic information environment that formed part of the backstory of the fracking revolution might appear hopelessly inefficient—far from the coordinated, duplicative-investment-avoiding world that Kitch suggested as an ideal.[401] But this environment might have been crucial to providing independents like Mitchell with the freedom, information, and incentives needed to generate the late 1990s' breakthrough. If obvious candidates in government or the private sector had succeeded in streamlining research and development, the result might have been substantial abandonment of shale gas development altogether.[402]

Circumstances nurturing a less than streamlined environment for innovation included more than the government research and funding, tax and regulatory relief, and infrastructure support discussed above.[403] Complementary assets well localized in space—namely, land and mineral rights—played a vital role in sustaining a plural information environment in which players could benefit from not only their own knowledge but also that of others, albeit perhaps with some delay. Acting in accordance with a balance of competing private interests, government and GRI policies, and industry norms, private parties like Mitchell commonly pursued a mixed-information strategy in which they held some information tight but disclosed much to others.[404] The

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398 *See supra* Part III.A.

399 *See* Merges & Nelson, *supra* note 368, 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.").

400 *See supra* text accompanying notes 336–62.

401 *See supra* note 365 and accompanying text.

402 *See, e.g.*, Merrill, *supra* note 109, at 976 (noting that, although "the U.S. Department of Energy has channeled billions of dollars in grants to promote new sources of energy," "comparatively little . . . has been devoted to the development of new oil and gas extraction techniques"); *supra* text accompanying note 312 (discussing Chevron's abandonment of the field as late as the 1990s).

403 *See supra* Part III.

404 *See supra* Part IV.B.

result was a leaky information environment, free from patent absolutism, although not free from patents, in which a significant amount of knowledge sloshed about speedily and widely enough to provide players such as Mitchell with crucial pieces of knowledge at critical times.[405]

5. Innovation in Governance

The story of the fracking revolution and ensuing boom also suggests the importance of progressive adaptation of government policies as a technology and its scale of implementation move from infancy to maturity.[406] After a technology has become established, private actors might no longer need facilitators of innovation such as tax or regulatory relief to use and further refine it. Further, failure to recalibrate regulation in light of large increases in a technology's use can risk not only immediate economic and environmental harm but also a backlash that could stymie technological development for decades.[407] Local backlash against fracking and related activities has already occurred, and even the city of Denton, Texas, located in the heart of the area where Mitchell Energy made its shale gas breakthroughs, has voted to ban fracking.[408]

Many of the causes of this backlash are now notorious. The shale gas boom has a darker side, often locally concentrated, that contrasts with its substantial benefits. As mentioned earlier, social costs in production areas have included

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405 *See supra* Part IV.B.

406 *Cf.* JOSH LERNER, BOULEVARD OF BROKEN DREAMS: WHY PUBLIC EFFORTS TO BOOST ENTREPRENEURSHIP AND VENTURE CAPITAL HAVE FAILED—AND WHAT TO DO ABOUT IT 146–47 (2009) (discussing the need for regular evaluation of the value of government programs to promote entrepreneurship, including periodic assessment of "whether the economic rationales that justified [a] program's creation still apply").

407 *Cf.* JARED DIAMOND, COLLAPSE: HOW SOCIETIES CHOOSE TO FAIL OR SUCCEED 202 (2005) (explaining Icelandic society's technological and social conservatism as a product of historical experience that led to the conclusion that Iceland "is not a country in which [the inhabitants] can enjoy the luxury of experimenting").

408 *See* Max B. Baker, *Denton Leaders Submitting Fracking Ban to the Voters*, STAR-TELEGRAM (Dallas) (July 16, 2014, 8:36 AM), http://www.star-telegram.com/2014/07/15/5973163/denton-fracking-ban-hearing-draws.html ("Denton is in the middle of the Barnett Shale . . . ."); Jim Malewitz, *Denton Bans Fracking, but Challenges Almost Certain*, TEX. TRIB., Nov. 5, 2014, http://www.texastribune.org/2014/11/05/denton-bans-fracking-spurring-bigger-clashes/ (reporting that Denton's vote "to ban hydraulic fracturing" has "se[t] up a high-profile property rights clash likely to be fought in courtrooms and the [Texas] Legislature"); *cf.* *Unconventional Gas in Europe: Frack to the Future*, ECONOMIST, Feb. 2, 2013, at 53, *available at* http://www.economist.com/news/business/21571171-extracting-europes-shale-gas-and-oil-will-be-slow-and-difficult-business-frack-future (noting temporary or indefinite bans on fracking or shale gas extraction in France, the Netherlands, Luxembourg, North Rhine-Westphalia, the Czech Republic, and Bulgaria).

chemical spills, increased crime and drug use, boomtown shortages of social infrastructure, and air pollution.[409] Independent producers that spearheaded the boom have not always been responsible stewards. They can be underinsured[410] and, through bankruptcy, potentially relatively judgment proof in the event of environmental or human damages.[411] Further, they have sometimes extracted deals for land or mineral rights that have later left landowners feeling betrayed.[412] Finally, although natural gas is often presented as a "bridge fuel" to a better environmental future,[413] the shale gas boom has arguably diverted effort from development of even more environmentally friendly technologies and has fed technological developments that have also generated a boom in the production of other, non-"bridge" fossil fuels such as shale oil.[414]

These downsides of the fracking revolution's aftermath counsel that policymakers should consider in advance how to mitigate often all too

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409 *See supra* text accompanying notes 262–70.

410 *See* Bhavini Kamarshi, Jason B. Kurtz & Richard Soulsby, *Fracking: Considerations for Risk Management and Financing*, MILLIMAN (June 21, 2012), http://www.milliman.com/insight/insurance/Fracking-Considerations-for-risk-management-and-financing/ (noting "the hundreds of small companies active in shale gas production with typically minimal pollution liability coverage"). In the context of fracturing, some insurance companies have suggested that they are unwilling to insure any companies, large or small. *See* David A. Dana & Hannah J. Wiseman, *A Market Approach to Regulating the Energy Revolution: Assurance Bonds, Insurance, and the Certain and Uncertain Risks of Hydraulic Fracturing*, 99 IOWA L. REV. 1523, 1560–61 & nn.154–155, 1574 (2014).

411 *See* Dana & Wiseman, *supra* note 410, at 1558 ("Unconventional well operations to date have involved many small LLC enterprises that could be defunct or insolvent if sued years after well abandonment or closure."); *see also* City of Midland's Motion for Estimation of Claims for Purpose of Allowance, Voting, and Determining Plan Feasibility, and Request for Determination that Remediation Claim is Entitled to Administrative Expense Priority at 2–3, *In re* Heritage Consol., LLC, Bankr. No. 10-36484 HDH-11 (Bankr. N.D. Tex. Nov. 15, 2010), ECF No. 256 (describing a case in which a company accepted oil and gas wastes into an injection well and entered bankruptcy after polluting the water supply).

412 *Cf.* Complaint at ¶¶ 7–9, Koonce v. Chesapeake Exploration, LLC, No. 2012-CV-136 (Ohio Ct. Com. Pl., Columbiana Cnty., Mar. 7, 2012) (a complaint in which plaintiffs alleged that "[t]he leasing strategy utilized by Defendant Chesapeake, including Anschutz, is to dispense land agents that canvass specific counties or townships with the intent of persuading landowners to enter into oil and gas leases" and that "land agents concealment, failure to disclose, and/or active misrepresentation of material facts, resulted in many landowners entering into oil and gas leases in which they received less than 1% of the fair market value for the up-front Signing Bonus payments that are currently being paid in Columbiana County"). The Defendant's removed this case to the Northern District of Ohio on March 27, 2012. *See* Notice of Removal, Koonce v. Chesapeake Exploration, LLC, No. 4:12-CV-00736-JRA (N.D. Ohio Mar. 27, 2012), ECF No. 1.

413 *See, e.g.*, Richard J. Pierce, Jr., *Natural Gas: A Long Bridge to a Promising Destination*, 32 UTAH ENVTL. L. REV. 245 (2012). *But see* Russell Gold, *The Siren Song of Natural Gas*, WALL ST. J., Mar. 26, 2012, http://online.wsj.com/article/SB10001424052702304636404577301111353242458.html ("[T]he bridge is looking longer and longer, spanning decades into the future.").

414 For a comparison of air emissions from natural gas, coal, and oil—showing lower emissions from natural gas for many pollutants—see U.S. ENERGY INFO. ADMIN., *supra* note 59, at 58 tbl.2.

predictable dislocation and damage from the widespread adoption of new technologies. Although governments cannot be expected to anticipate all the positive or negative effects of innovation, accumulated experience should enable governments to recognize that booms in resource extraction will likely have negative impacts and therefore should be monitored with care.[415] In the case of the shale gas boom, state and federal governments' adaptation of regulation to the new scale of shale-gas related activities has sometimes lagged frustratingly behind the times. Even now, the federal government has failed to invest in a national cost–benefit analysis for unconventional gas development.[416] To facilitate greater responsiveness to a gathering boom, government might helpfully act anticipatorily—for example, by equipping pre-boom packages of tax or regulatory relief with sunset provisions, requirements of regular regulatory review, or activity-level triggers that ratchet relief downward or require revisitation of its intensity as the scope of relevant activities escalates. In such ways, the government might more effectively induce reconsideration and adjustment of policies as circumstances change, thereby perhaps preventing the polity from blithely riding the wave of a boom until a potentially excessive backlash results.

Innovation in governance might also require attention to the peculiarities of a particular technological innovation or its implementation. The nature of new technologies and their modes of exploitation might demand more than straightforward adjustment of existing regulation in light of growth in the volume or intensity of related activities. For example, tax structures might need qualitative revision to generate funds needed to address localized impacts on physical infrastructure, social services, or the environment. In areas experiencing an economic boom, restrictions on local or state tax increases can complicate the task of collecting revenue to maintain local roads.[417] Moreover,

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415 *See* Wiseman, *supra* note 262 (suggesting that governments regulating an activity should anticipate that the activity might expand in scale and should implement mechanisms to address resulting impacts, such as provisions for automatically ratcheting up agency enforcement staff).

416 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. NERA ECON. CONSULTING, MACROECONOMIC IMPACTS OF LNG EXPORTS FROM THE UNITED STATES (2012), http://energy.gov/sites/prod/files/2013/04/f0/nera_lng_report.pdf; U.S. ENERGY INFO. ADMIN., U.S. DEP'T OF ENERGY, EFFECTS OF INCREASED NATURAL GAS EXPORTS ON DOMESTIC ENERGY MARKETS (2012), http://energy.gov/sites/prod/files/2013/04/f0/fe_eia_lng.pdf.

417 Ana Campoy, *Drilling Strains Rural Roads: Counties Struggle to Repair Damage from Heavy Trucks in Texas Energy Boom*, WALL ST. J., July 27, 2012, at A3, *available at* http://www.wsj.com/articles/SB10000872396390444840104577551223860569402 ("Texas laws effectively limit tax-revenue increases [for county governments] to less than 8% a year . . . ."); *cf.* SEAN O'LEARY, W. VA. CTR ON BUDGET & POLICY,

as operators increasingly drill long laterals, the average environmental impact of individual wellheads could rise with the average amount of oil or gas flowing out of each wellhead. Taxes allocated on a per-wellhead basis might need adjustment to tie resulting revenues more closely to actual production or expected environmental impacts.[418] In short, the fracking revolution and ensuing boom might require short- and long-term rethinking of how drilling activities are taxed.

The rise of an activity dominated by independents—as hydraulic fracturing and horizontal drilling of unconventional resources have generally been[419]—also might call for more careful or innovative regulation in light of independents' potentially higher discount rates and potentially greater tendencies to take risks that could generate serious, long-term environmental externalities.[420] Some of the very characteristics that make independents well

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POLICY BRIEF: IMPACTS OF GAS DRILLING IN WETZEL COUNTY 9 (2014), http://www.wvpolicy.org/wp-content/uploads/2014/04/Impacts-of-Drilling-in-Wetzel-County.pdf ("[I]n Arkansas, the Highway and Transportation Department found that the damage caused to state highways by drilling-related traffic will cost $218.7 million to repair, but the Department has only received one-seventh of that amount from the increase in severance tax revenue.").

418 Many states already have severance taxes that are tied to the value of oil and gas produced. *See* Jacquelyn Pless, *Oil and Gas Severance Taxes: States Work to Alleviate Fiscal Pressures Amid the Natural Gas Boom*, NAT'L CONF. ST. LEGISLATURES (Feb. 2012), http://www.ncsl.org/research/energy/oil-and-gas-severance-taxes.aspx (comparing current state severance taxes). Pennsylvania, on the other hand, recently implemented an impact fee that is based on the number of wells "spud" (drilled). *See* 58 PA. CONS. STAT. ANN. §§ 2302–2315, 3501–3504 (West, Westlaw current through 2014 Reg. Sess.) (providing for an unconventional gas well fee and its distribution). Although the implementation of a tax based on the number of wells could have reflected a political compromise rather than a genuine effort to address impacts (Pennsylvania's governor resisted a severance tax, fearing that it would discourage production), it also could have reflected a belief that properly designed per-wellhead taxes better address impacts, or do so more accurately than taxes on production. *See id.* §§ 2302–2315; Susan Phillips, *Corbett Says Taxing Natural Gas May Be a Future Option*, STATEIMPACT (Oct. 13, 2014, 11:05 AM), https://stateimpact.npr.org/pennsylvania/2014/10/13/corbett-says-taxing-natural-gas-may-be-a-future-option/ ("Corbett continues to oppose this [severance] tax for now, saying it would cut too much into the drillers bottom line, causing them to move out of state.").

419 *See supra* note 178 and accompanying text; *see also* Collin Eaton, *Big Oil Comes Up Short in Shale*, FUELFIX (Apr. 13, 2014, 2:13 AM), http://fuelfix.com/blog/2014/04/13/big-oil-comes-up-short-in-shale/ ("In terms of acreage in the three biggest shale-oil plays, small players outweigh the majors 5-to-1, according to a FuelFix analysis of data compiled by Bloomberg.").

420 *See supra* notes 409–12 and accompanying text. In this more mature stage of the oil and gas boom, many of the current producers, whether technically qualifying as independents or not, are in fact relatively large companies, but smaller companies remain important players. *See* Dana & Wiseman, *supra* note 410, at 1558 n.140 (describing the dominance of a small number of large companies in the Marcellus Shale play but the continued importance of small entities and the importance of subcontractors); *see also Statewide Data Downloads by Reporting Period*, PENN. DEPT. ENVTL. PROTECTION OIL & GAS REPORTING, https://www.paoilandgasreporting.state.pa.us/publicreports/Modules/DataExports/DataExports.aspx (last visited Mar. 5, 2015) (agree to informational statement, select hyperlink "CSV" under "Production" for "Jan-Jun 2014

suited to bringing about a boom in the exploitation of an unconventional resource might make them questionable long-term stewards. Further, even when producers are relatively large and stable companies, inadequate oversight of contractors and subcontractors that themselves lack expectations of long-term ties to communities can lead to similar concerns. Although the environmental performance of vertically integrated energy majors has been far from perfect,[421] such companies, which likely expect to be in business for decades, might often recognize potential savings of cost and risk from good environmental practices[422] and can have substantial interests both in general reputation[423] and, more concretely, in maintaining good social standing with communities whose support or acquiescence is necessary to enable long-term production, including the drilling and fracturing of more wells or reworking of wells as production declines.[424] In contrast, smaller actors whose independent existence is more precarious might often be expected to lack equally strong forward-looking incentives.

B. Applications Abroad and to Other Technologies

As indicated above, the meaning and meaningfulness of lessons drawn from the United States' fracking revolution are context dependent.

(Unconventional Wells)") (showing that comparatively large producers like Chesapeake operate the largest numbers of wells, with Chesapeake operating approximately 858 wells out of 7707, Chevron operating 390 wells, and XTO operating 239 wells).

421 *Cf.* NAT'L COMM'N ON THE BP DEEPWATER HORIZON OIL SPILL & OFFSHORE DRILLING, DEEPWATER: THE GULF OIL DISASTER AND THE FUTURE OF OFFSHORE DRILLING, REPORT TO THE PRESIDENT 90 (2011), *available at* http://www.gpo.gov/fdsys/pkg/GPO-OILCOMMISSION/pdf/GPO-OILCOMMISSION.pdf (concluding that "[a] blowout in deepwater was not a statistical inevitability" and blaming the blowout at the Deepwater Horizon's Macondo well on management failures of BP and its contractors).

422 Jennifer L. Molnar & Ida Kubiszewski, *Managing Natural Wealth: Research and Implementation of Ecosystem Services in the United States and Canada*, 2 ECOSYSTEM SERVS. 45, 52 (2012) ("Whether a local US or Canadian company or multi-national firm, corporations rely on ecosystem services to maintain their bottom line, including by providing raw materials, protecting facilities from natural disasters, and regulating regional or global climate.").

423 *Beware the Angry Birds: In the Social-Media Age, Bosses' Careers Are More Vulnerable Than Ever*, ECONOMIST, Oct. 11, 2014, http://www.economist.com/news/business/21623676-social-media-age-bosses-careers-are-more-vulnerable-ever-beware-angry-birds (contending that "[t]he stock market is more sensitive to reputational disasters than ever before," and reporting that "[a] 2013 survey of 300 executives about the risks facing their companies by Deloitte, a consulting firm, put reputational ones at the top").

424 *See* DIAMOND, *supra* note 407, at 360 (discussing "reasons why Chevron and the handful of other big international oil companies have been taking environmental issues seriously"); *cf.* Molnar & Kubiszewski, *supra* note 422, at 52 (observing that maintenance of "ecosystem health" can decrease costs and risk for relevant companies and can also have "indirect connections [to companies' bottom lines], including through a company's license to operate in a landscape, brand reputation, or community relations").

Nonetheless, a number of the lessons might helpfully inform efforts to advance other technologies or, to the extent desirable, to advance the spread of the fracking revolution abroad.

1. *International Transfer*

Up to this point, the United States has almost singlehandedly led the fracking revolution,[425] but there are abundant fuel-rich shale formations worldwide,[426] and many countries are looking to exploit them.[427] Foreign companies have attempted to gain access to U.S. know-how by investing heavily in companies operating in the United States[428] and by forming joint ventures with U.S. companies[429]—both approaches serving as potential means to gain technologies and skills that might apply to formations abroad.[430] But although foreign shale gas development will not require reinvention of the most basic aspects of the fracking revolution, it will likely demand significant additional innovation as producers confront different sets of geologies, local environments, and resource constraints.

In overcoming likely technical obstacles to a shale gas boom abroad, foreign countries might benefit from the lessons discussed in Part V.A. In particular, they might facilitate their own fracking revolutions by adopting policies to support a diverse innovation ecosystem, to provide a correspondingly broad array of government supports for innovation, and to

425 Jeff McMahon, *Six Reasons Fracking Has Flopped Overseas*, FORBES (Apr. 7, 2013, 9:00 AM), http://www.forbes.com/sites/jeffmcmahon/2013/04/07/six-reasons-fracking-has-flopped-overseas/ ("Shale gas deposits have been found in Poland, Argentina, China, Great Britain and other countries, but only the United States has fracked its shale gas into a national energy boom.").

426 *Shale Oil and Gas Resources are Globally Abundant*, U.S. ENERGY INFO. ADMIN. (Jan. 2, 2014), http://www.eia.gov/todayinenergy/detail.cfm?id=14431 (reporting data indicating that shales contain 32% of the world's wet natural gas reserves).

427 *See* Editorial, *OPEC Versus the Shale Revolution*, BUS. TIMES SING., May 29, 2013 (noting that "Argentina, Australia, Canada, China, Estonia and Russia, among others," are "tapping into shale").

428 *See Foreign Investors Play Large Role in U.S. Shale Industry*, U.S. ENERGY INFO. ADMIN. (Apr. 8, 2013), http://www.eia.gov/todayinenergy/detail.cfm?id=10711 (showing that "[j]oint ventures by foreign companies accounted for 20%" of all investment in U.S. shale plays between 2008 and 2012).

429 John Kemp, *U.S. Fracking Giant Goes to China*, REUTERS, June 11, 2014, *available at* http://www.reuters.com/article/2014/06/11/china-shalegas-idUSL5N0OS3QF20140611 (reporting on "a joint venture between FTS International and Sinopec"); *id.* (noting that "Helmerich & Payne, one of the largest drillers in North America," would "transfer 10 of its modern FlexRigs to exploit Argentina's Vaca Muerta shale under a five-year contract with state-owned YPF, which has teamed up with Chevron").

430 *See Foreign Investors Play Large Role in U.S. Shale Industry*, *supra* note 428 (noting that "foreign companies gain experience in horizontal drilling and hydraulic fracturing" by investing in joint ventures with U.S. companies).

encourage mixed strategies for information management that allow substantial incentives for innovation to coexist with information flows and spillovers. But a variety of constraints, including constraints of politics and culture, might make it difficult for other countries to follow the United States' example. Most notably, the United States is an outlier in the extent to which its mineral rights are privately owned.[431] Other countries' minerals are generally state owned, and state ownership and regulation can be a hurdle to establishing a diverse and decentralized environment of industry players.[432]

China is an illustrative case. China has been estimated to have the largest shale gas reserves of any country.[433] But much of its known shale gas is located in mountainous areas,[434] where transporting water to wells for fracturing might be difficult. Further, the geology of the shales differs from that of typical U.S. sites[435] in ways that tend to complicate resource extraction.[436] Moreover, as a nation, China is already much more water stressed than the United States.[437] These and other conditions suggest a need for further innovation in relatively underdeveloped techniques of waterless fracturing.[438] New pipeline infrastructure also will be required, thus suggesting the need for large infrastructural investments similar to those made in the United States.[439]

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431 Merrill, *supra* note 109, at 977 (observing that the "United States is something of an outlier" in "that mineral rights in the United States are predominantly privately owned").

432 *See id.* at 977–78 (noting that "[m]ost other countries follow the rule that subsurface minerals belong to the state" and thus have access to minerals "controlled by a centralized bureaucracy").

433 David Biello, *Can Fracking Clean China's Air and Slow Climate Change?*, SCI. AM. (Jan. 27, 2014), http://www.scientificamerican.com/article/can-fracking-clean-chinas-air-and-slow-climate-change/ ("By any estimate, China appears to have the largest reserves of shale gas in the world.").

434 Catherine T. Yang, *China Drills Into Shale Gas, Targeting Huge Reserves Amid Challenges*, NAT'L GEOGRAPHIC, Aug. 8, 2012, http://news.nationalgeographic.com/news/energy/2012/08/120808-china-shale-gas/.

435 *See id.* (noting differences in clay content).

436 Biello, *supra* note 433 ("[T]he geology itself is more challenging [in China] than in the U.S.").

437 DIAMOND, *supra* note 407, at 364 ("By world standards, China is poor in fresh water, with a quantity per person only one-quarter of the world average value."); Yang, *supra* note 434.

438 *See* Stephen Rassenfoss, *In Search for the Waterless Fracture*, J. PETROLEUM TECH., June 2013, *available at* http://www.mydigitalpublication.com/article/In+Search+Of+The+Waterless+Fracture/1408907/0/article.html ("For now, the only practical waterless options are hydraulic fracturing using oil and natural gas liquids (NGL) most of it in a select group of formations in Canada, where adding water has long been thought to reduce gas production.").

439 *See* Yang, *supra* note 434 ("China lacks the extensive pipeline network that has enabled the United States to so quickly bring its new natural gas bounty to market.").

China also faces challenges in developing an innovation ecosystem as diverse and vibrant as that in the United States. China's efforts to dramatically increase its shale gas production might test the limits of what state-led development through giant companies such as Sinopec[440] can accomplish. Although development by state-owned firms might facilitate financing and favorable regulatory treatment, excessive reliance on large energy companies might stifle creativity and make it difficult for China to replicate the U.S. fracking revolution's success.[441] China is trying to counter this concern by permitting non-state-owned companies to engage in shale gas exploration and by lightening the regulatory grip on prices for shale gas.[442] Other countries following the typical global model of state ownership of mineral resources and development of those resources by a limited number of large companies[443] might need to take similar steps.[444]

With respect to regulatory adaptation, state ownership and development dominated by large companies might make matters easier by facilitating responsiveness to changes in government policy but could also make matters worse by increasing the risk of regulatory capture that prevents favorable changes in government policy from occurring. Regardless, lessons from negative environmental and social consequences of the United States' oil and gas boom might place foreign countries at a comparative regulatory advantage. For example, today's greater awareness of the potential environmental and seismic effects of extraction-related activities could enable regulators abroad to require better care in their initial deployment, especially in areas of known environmental or seismic sensitivity.[445]

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440 *See* Eric Ng, *Sinopec Leads China's Shale Gas Revolution With Successful Drilling*, S. CHINA MORNING POST (Apr. 24, 2014, 2:37 AM), http://www.scmp.com/business/commodities/article/1495391/sinopec-leads-chinas-shale-gas-revolution-successful-drilling.

441 *See supra* Part III.

442 Biello, *supra* note 433 ("The Chinese are also attempting to mimic the U.S. in allowing companies other than the state-owned oil giants to begin exploring for shale gas, legally designating the resource as one that can be independently mined.").

443 *See* Ernest E. Smith & John S. Dzienkowski, *A Fifty-Year Perspective on World Petroleum Arrangements*, 24 TEX. INT'L L.J. 13, 30–32 (1989) (discussing typical forms of agreements for development of state-owned mineral resources).

444 *Cf. Shale Gas in Mexico: On Shaky Ground*, ECONOMIST, May 3, 2014, http://www.economist.com/news/americas/21601518-mexicos-prospective-shale-boom-will-be-long-time-coming-shaky-ground (reporting on Mexican efforts to implement "a constitutional overhaul . . . which, for the first time in 75 years, lets private companies drill for hydrocarbons").

445 *See, e.g.*, COUNCIL OF CANADIAN ACADS., ENVIRONMENTAL IMPACTS OF SHALE GAS EXTRACTION IN CANADA 18–19 (2014), http://www.scienceadvice.ca/uploads/eng/assessments%20and%20publications

In short, other countries might have difficulty replicating the United States' success in generating a shale gas boom and will likely succeed only if they can successfully adjust the United States' formula to their particular circumstances. But as seen with China, countries are already trying to benefit from the fracking revolution's positive and negative lessons.

2. *Renewable Energy*

Lessons from the fracking revolution can also have value in other energy sectors. The policies that helped spur the shale gas boom have particular relevance in technology areas that face a similar set of hurdles and opportunities. No field may fit this set of circumstances better than renewable energy. Indeed, just as skepticism of the commercial viability of shale gas long caused oil and gas majors to eschew its development,[446] many critics currently discount the economic prospects of renewables.[447] But the story of the fracking revolution teaches us that, whatever the validity of such discounting with respect to renewables' immediate economic prospects, policymakers should not consider it conclusive for the longer term. As with shale gas, wind and solar technologies have the potential to fundamentally alter world energy markets and provide rich, long-term economic and environmental benefits.[448] But like shale gas, wind and solar technologies will require a proper array of supporting factors to experience a transformative boom.

%20and%20news%20releases/shale%20gas/shalegas_fullreporten.pdf (noting that certain underexplored Canadian shales are in environmentally sensitive forests or agriculturally productive regions); Biello, *supra* note 433 (noting that areas such as China's Sichuan Province "are already prone to earthquakes").

446 *See* Hinton, *supra* note 6, at 234 (noting that, whereas Mitchell Energy persisted in efforts "to produce gas from a type of rock that most people thought was commercially hopeless," "[m]ajor companies had long since decided that there were far better places for exploration than north Texas").

447 *See, e.g.*, PHILLIP BROWN & GENE WHITNEY, CONG. RESEARCH SERV., R41954, U.S. RENEWABLE ELECTRICITY GENERATION: RESOURCES AND CHALLENGES 1, 38–39 (2011), *available at* http://fas.org/sgp/crs/misc/R41954.pdf (entertaining the possibility of renewables proving at least partly feasible, but noting, but noting the existence of various "deployment barriers," including "cost," demand for "significant quantities of materials and other natural resources," and the need for "investments in specialized infrastructure"); *cf. A Sharper Focus On the Bottom Line*, SHELL (June 2014), http://www.shell.com/global/aboutshell/media/speeches-and-articles/articles/sharper-focus-on-the-bottom-line.html (quoting Shell CEO Ben van Beurden as saying, "When it comes to solar and wind, we've tried to be successful but it did not work for a company with our particular skills and expertise").

448 *See, e.g.*, INT'L ENERGY AGENCY, GOLDEN RULES FOR A GOLDEN AGE OF GAS: WORLD ENERGY OUTLOOK SPECIAL REPORT ON UNCONVENTIONAL GAS 91 (2012), http://www.worldenergyoutlook.org/media/weowebsite/2012/goldenrules/WEO2012_GoldenRulesReport.pdf (concluding, based on previous reports and more recent data, that "natural gas cannot on its own provide the answer to the challenge of climate change").

Renewable energies have experienced substantial progress, both in terms of technological development and technology adoption,[449] but they have not yet experienced the sort of great leap forward that yielded the shale gas boom. This has been true in the United States despite the fact that renewable energies have enjoyed significant government support, in substantial ways comparable to, if not greater than, the support directed toward development of shale gas during the thirty years from the mid-1970s creation of DOE and GRI to the start of the shale gas boom.[450] Government entities like the National Renewable Energy Laboratory have long spearheaded projects similar to those of the Gas Research Institute or DOE in relation to shale gas, including the extensive mapping of areas with abundant sunlight and wind[451] and the formation of public–private partnerships to push forward relevant technologies.[452] Renewables have also received tax relief such as a production tax credit.[453] Likewise, they have been targeted for regulatory relief, perhaps most prominently through efforts to speed processes of government permitting and approval.[454] Finally, renewable-energy developers have access to a private property rights system not entirely dissimilar to that which enabled shale gas developers to appropriate value by buying and selling complementary assets: renewable-energy developers can buy land and perhaps also air rights that, at least in theory, could be made more valuable through innovations that make wind or solar technologies more profitable.

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449 *Cf. Wind Industry Installs Almost 5,300 MW of Capacity in December*, U.S. ENERGY INFO. ADMIN. (Feb. 11, 2013), http://www.eia.gov/todayinenergy/detail.cfm?id=9931 (showing that in 2008, 2009, and 2012, there were more installations of new wind energy capacity than of any other form of electric generating capacity, including natural gas).

450 *But see* Melissa Powers, *Sustainable Energy Subsidies*, 43 ENVTL. L. 211, 214 (2013) ("[H]istorical fossil fuel subsidies eclipse recent government support for renewable energy.").

451 *See Dynamic Maps, GIS Data, and Analysis Tools*, NAT'L RENEWABLE ENERGY LAB., http://www.nrel.gov/gis/maps.html (last modified Feb. 18, 2015).

452 *Working with Us*, NAT'L RENEWABLE ENERGY LAB., http://www.nrel.gov/wind/working_with.html (last modified Feb. 3, 2015) (discussing public–private efforts "to research, design, and build advanced wind energy technologies").

453 *E.g.*, American Taxpayer Relief Act of 2012, Pub. L. No. 112-240, tit. IV, §§ 406(a), 407(a), 126 Stat. 2313, 2340–41.

454 *See, e.g.*, Residential, Business, and Wind and Solar Resource Leases on Indian Land, 77 Fed. Reg. 72,440 (Dec. 5, 2012) (codified as 25 C.F.R. § 162 (2014)) (simplifying leasing of federal land); Renewable Energy Development by the Department of the Interior, Order No. 3285 (Feb. 22, 2010), *available at* http://www.drecp.org/whatisdrecp/docs/DOI_Secretarial_Order_3285_A1.pdf (creating a task force to speed the renewable-energy permitting); *Overview: Offshore Wind Energy Development off the Atlantic Coast*, U.S. DEP'T OF INTERIOR (2010), http://www.doi.gov/news/pressreleases/upload/02-07-10-wea-fact-sheet.pdf (announcing the "Smart from the Start Initiative" to help speed up the process of approving offshore wind projects).

But government support has not always been steady or effective. Patience and stable sources of support like those enjoyed in the lead-up to the fracking revolution have often been lacking. Tax relief for renewables has been notoriously fickle,[455] frustrating efforts to foster the sort of sustained dedication to resource development that marked Mitchell Energy's long toil in the Barnett Shale.[456] Moreover, even under a somewhat streamlined system for renewable-energy approvals, the bureaucracy associated with development approval has often seemed to move too slowly, inviting Jeffrey Thaler's description of relevant government agents as "fiddling as the world floods and burns."[457]

Moreover, private property rights in land and air have so far proven less useful as complementary assets to promote innovation. In the case of wind energy, this is perhaps in part because, in contrast to states' general treatment of mineral rights,[458] state governments have largely prevented the effective severance of air rights from rights in the land's surface.[459] A more general problem might be that, in contrast to rights in previously unknown or non-extractable minerals, the relevant surface and air rights already have many existing valuable uses and thus have a value to which positive developments in wind and solar energy will likely add only incrementally. In contrast, a technological development that makes an underground mineral newly extractable might turn previously worthless mineral rights into an effective gold mine, the result being a much more substantial return on the innovator's investment. Without a prospect for such a high rate of return, private land and air rights might be a comparatively ineffective means of appropriating value in renewable-energy innovation. Although some owners of land or air rights

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455 *See* Uma Outka, *Environmental Law and Fossil Fuels: Barriers to Renewable Energy*, 65 VAND. L. REV. 1679, 1691–93 (2012) (describing the ups and downs of the production tax credit for renewable energy).

456 *See* NAT'L ACAD. OF SCIS., ELECTRICITY FROM RENEWABLE RESOURCES: STATUS, PROSPECTS, AND IMPEDIMENTS 12–13 (2010), *available at* http://www.nap.edu/download.php?record_id=12619# (highlighting the need for "sustained, consistent, long-term policies that provide for production tax credits, market incentives . . . to support significant growth of the market for renewable electricity").

457 Jeffrey Thaler, *Fiddling as the World Floods and Burns: How Climate Change Urgently Requires a Paradigm Shift in the Permitting of Renewable Energy Projects*, 42 ENVTL. L. 1101 (2012).

458 *See* John Lowe, *The Easement of the Mineral Estate for Surface Use: An Analysis of its Rationale, Status, and Prospects*, 39 ROCKY MT. MIN. L. INST. 4-1, 4-3 (1993) (noting courts' grant of "broad application to the general rule that the mineral owner or lessee has an implied right to use the surface").

459 *But cf.* Ernest E. Smith & Becky H. Diffen, *Winds of Change: The Creation of Wind Law*, 5 TEX. J. OIL, GAS & ENERGY L. 165 (2010) (noting that Texas wind developers are in some cases obtaining only air rights and that Texas courts will likely apply the reasonable use doctrine from oil and gas to the wind energy context).

might be able to obtain high returns,[460] these happy results might be significantly less common than for owners of rights in minerals.

In any event, even if renewable-energy development were supported by complementary assets comparable to mineral rights, renewable-energy developers would face substantial infrastructure and market-access difficulties reminiscent of those facing independent natural gas producers before the 1970s.[461] The first and most significant problem for renewable-energy development comes in the form of inadequate transmission infrastructure. Just as operators drilling for natural gas once lacked sufficient access to interstate pipelines, renewable-energy developers face high hurdles in the form of continuing transmission constraints. Many of the best places for generating renewable energy are in remote areas of the United States, and developers of renewable-energy technologies therefore need access to transmission lines connecting their project sites to places of substantial electricity demand.[462]

Unfortunately for renewable-energy developers, there are multiple impediments to the construction of adequate interstate and regional transmission lines. First, unlike interstate natural gas pipelines, for which FERC approves the routes and grants developers eminent domain authority,[463] no federal agency has authority over the actual siting of interstate transmission lines.[464] FERC has ordered that owners and operators of transmission lines plan for the regional expansion and operation of transmission lines,[465] but FERC's authority in this area ends at planning. Siting and eminent domain power lies solely with state and local governments, a situation that predictably generates coordination problems. A further problem comes from the fact that,

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460 *See, e.g.*, OFFICE OF ENERGY EFFICIENCY & RENEWABLE ENERGY, U.S. DEP'T OF ENERGY., DOE/GO-102001-1284, WIND POWERING AMERICA 2–3 (2001), http://www.nrel.gov/docs/fy01osti/29895.pdf (describing fifth-generation farmers in Minnesota who were "barely making a living" but now receive "over $40,000 in revenue" from a wind farm on their property, and stating hopes to have wind energy account for 5% of federal electricity use, and estimating that this would provide "$1.2 billion in new income" for landowners).

461 *See supra* text accompanying notes 124–39.

462 Alexandra B. Klass & Elizabeth J. Wilson, *Interstate Transmission Challenges for Renewable Energy: A Federalism Mismatch*, 65 VAND. L. REV. 1801, 1811 (2012) ("[T]he best wind resources are often located far from electricity demand centers . . . .").

463 *See supra* text accompanying note 135.

464 *See* Jim Rossi, *The Trojan Horse of Electric Power Transmission Line Siting Authority*, 39 ENVTL. L. 1015, 1017 (2009) ("The determination of siting—or the location of a line and its approval, including eminent domain authority—remains largely within the hands of state regulators.").

465 Transmission Planning and Cost Allocation by Transmission Owning and Operating Public Utilities, 76 Fed. Reg. 49,842 (Aug. 11, 2011).

even though FERC requires that all transmission line owners and operators offer their lines to any generators who need to use them on an open-access, non-price-discriminatory basis,[466] there are bottlenecks in the use of such lines that at least partly reflect the coordination problems discussed above. These bottlenecks can result in generators being denied effective access—or charged premium fees for access—because they are too late in a usage queue ordered on a first-come, first-served basis.[467]

A second problem for renewable-energy developers comes in the form of barriers to the development of effective national markets. This problem is reminiscent of the prior caps on prices for natural gas sold interstate, which stymied the production of natural gas for out-of-state markets, including gas from unconventional resources such as shales.[468] Although FERC allows generators to charge a market-based rate for electricity in most parts of the country where FERC has determined that generators lack market power,[469] certain state laws and regulations prevent the effective operation of this otherwise open market. States determine where and whether a developer may build a power plant that will produce electricity—electricity that might be sold both wholesale (in which case FERC has jurisdiction over the transaction) and retail (in which case the state has jurisdiction over the sale).[470] This permits a situation like that in Florida, where the relevant public utility commission only certifies plant construction by generators providing electricity to retail customers in Florida.[471] The result for Florida is an effective prohibition on the construction of generation capacity directed solely toward the production of electricity for wholesale, out-of-state customers. Such state-based obstacles

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466 Promoting Wholesale Competition Through Open Access Non-discriminatory Transmission Services by Public Utilities; Recovery of Stranded Costs by Public Utilities and Transmitting Utilities, 61 Fed. Reg. 21,540 (May 10, 1996).

467 This "usage" queue is, in energy parlance, called "interconnection"—the process of initially connecting one's generation to transmission lines to that electricity can be sent through those lines. For an example of the difficulties of interconnecting wind farms despite FERC orders for uniform interconnection standards for wind, see Order On Rehearing and Compliance Filing, 143 FERC ¶ 61,050 (Apr. 18, 2013), *available at* http://www.ferc.gov/whats-new/comm-meet/2013/041813/E-14.pdf (describing the interconnection process for several wind generators).

468 *See supra* notes 151–56 and accompanying text.

469 *See* 76 Fed. Reg. 49,842 (describing the existing authority of wholesale sellers to charge market-based rates and refining certain rules).

470 *See* 16 U.S.C. § 824(b)(1) (2012) (granting the federal government certain power over electric generation, transmission, and sale but not "over facilities used for the generation of electric energy or over facilities used in local distribution or only for the transmission of electric energy in intrastate commerce").

471 Tampa Elec. Co. v. Garcia, 767 So. 2d 428 (Fla. 2000).

can seriously hinder the development of a robust national market in renewable energies, which are often principally associated with electricity generation.

Another market barrier to renewable energy can arise from state practices that cap at a "just and reasonable" level the rates that utilities may charge for electricity.[472] Although limiting prices to "just and reasonable" levels might seem relatively benign, it can have a comparatively adverse impact on use of renewable energy, an impact that could run contrary to the public interest. Some states effectively preclude reliance on renewables[473] by pegging "just and reasonable" caps to the cheapest sources of energy available. The results can be contrary not only to long term interests in renewable-energy innovation but also to more immediate public interest. Many consumers might be willing to pay a premium for the use of renewable energy,[474] and the apparent cheapness of other energy sources might be belied by comparatively high upfront costs that rate reviews neglect, such as costs of nuclear power plant construction.[475]

A chicken-and-egg problem can result from complications to renewable-energy investment, such as those fostered by inconsistent tax policies and unfavorable approaches to rate regulation. Potential builders of transmission lines that could serve renewable-energy generators become reluctant to build without assurance that there will be enough generators for their lines to serve. Potential generators do not want to build without assurance that adequate transmission capacity will be available. States like Texas[476] and

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472 *See generally* Robert R. Nordhaus, *Electric Power Regulation: Marking Partially-Regulated Markets Work*, 54 ADMIN. L. REV. 365, 367 (2002) (describing cost-of-service ratemaking by states).

473 *See, e.g.*, Matthew L. Wald & Tom Zeller, Jr., *Costs of Green Power Makes Projects Tougher Sell*, N.Y. TIMES, Nov. 7, 2010, at A1, *available at* http://www.nytimes.com/2010/11/08/science/earth/08fossil.html (describing three states that rejected renewable power on the basis of cost).

474 Lori A. Bird, Karlynn S. Cory & Blair G. Swezey, *Green Price Stability*, PUB. UTIL. FORT., Jan. 2009, at 42, 42 (noting that of the "utility green power programs" offered to consumers, where consumers may voluntarily choose to buy electricity generated from renewable sources at a premium, there is an average of 2% customer participation, "with the top programs averaging from 5 percent to 20 percent").

475 *Cf.* Kelley M. Gale et al., *Financing the Nuclear Renaissance: The Benefits and Potential Pitfalls of Federal & State Government Subsidies and the Future of Nuclear Power in California*, 30 ENERGY L.J. 497, 502 (2009) (noting that under some state nuclear power financing laws, "a utility can pass the construction costs for a new nuclear reactor along to ratepayers before the plant is completed by obtaining rate increases periodically during the construction process without regard to whether development stays on-budget or on-schedule").

476 TEX. UTIL. CODE ANN. § 39.904 (West Supp. 2014); 16 TEX. ADMIN. CODE § 25.173 (2014) (requiring the establishment of Competitive Renewable Energy Zones).

California[477] have sought to prevent such an unproductive standoff by identifying geographical areas having the best renewable-resource potential and mandating construction of transmission lines to them. More generally, a true renewable-energy boom might require greater federal coordination, perhaps along the lines of FERC's role in relation to gas pipelines[478] and pricing.[479] Moreover, to truly replace heavy reliance on more broadly established energy sources like fossil fuels, renewable energies such as wind and solar will likely require substantial advances in energy storage technology[480] or other innovations to address the intermittency of local sources of supply, such as innovations that enable transmission networks to better integrate renewable sources with different peak production times. As with the fracking revolution, patience, reliable sources of incentives, well-targeted government aid, and infrastructure all have important roles to play.

In sum, governments in the United States and abroad can use lessons from the fracking revolution in seeking to develop alternative technologies such as renewable energy. At the same time, however, policymakers need to be sensitive to the distinct and often changing circumstances that they and would-be innovators face. A large part of the fracking revolution's lessons about the value of policy adjustment and a diverse innovation ecosystem reflects likely needs for adaptability in both space and time. Ultimately, in spurring game-changing innovation, there is only so much one can learn by rote.

CONCLUSION

The story of the early twenty-first century's U.S.-centered boom in unconventional oil and gas development is far more complex than is often acknowledged. This story involved a wide array of actors beyond George Mitchell, a wide variety of technologies and innovations, moderate use of

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477 *Renewable Energy Transmission Initiative (RETI)*, CAL. ENERGY COMM'N, http://www.energy.ca.gov/reti/ (last visited Mar. 5, 2015) (describing "a statewide initiative to help identify the transmission projects needed to accommodate . . . renewable energy goals, support future energy policy, and facilitate transmission corridor designation and transmission and generation siting and permitting").

478 *See supra* text accompanying notes 133–36.

479 *See supra* text accompanying notes 137–47.

480 R.M. Dell & D.A.J. Rand, *Energy Storage—A Key Technology for Global Energy Sustainability*, 100 J. POWER SOURCES 2, 6 (2001) (noting that, whereas fossil fuels "are readily transportable" "energy stores," "most of the renewables (except for biomass and hydro) cannot be stored and cannot be transported to the place of use, except by first converting them to electricity" (emphasis omitted)).

patents, mixed practices of secrecy and information sharing, vital roles for private property rights in minerals and land, and a long history of government research support, tax benefits, and regulatory and tax exemptions. Intriguingly for innovation theory, a lack of patenting of critical aspects of the Mitchell synthesis of slickwater fracturing and directional drilling might well have contributed substantially to the new technologies' rapid adoption and spread through the actions of a large number of small, independent producers.

Moreover, technological innovations specific to drilling and fracturing are only part of the story behind the shale gas boom. Substantial spurs to the fracking revolution came from a number of other technological improvements that emerged before or alongside developments in drilling and fracturing.[481] Government policies played key roles, with a combination of direct research and funding,[482] partnerships with private players,[483] regulatory and tax relief,[484] and infrastructure development helping pave the way for the boom.[485] This convergence of facilitating factors provides lessons for policymakers looking to expand horizontal drilling and fracking internationally or to stimulate further innovation in other technologies, such as those relating to renewable sources of energy. As highlighted in Part V, these lessons include instruction on the importance of patience and reliability in seeking to promote game-changing innovations, the value of diverse innovation ecosystems and mixed information strategies, and ways in which governments and infrastructure can help foster and maintain such ecosystems and strategies.

In the renewable-energy context, the development and deployment of efficient, effective, and competitive renewable-energy technologies will require time and patience and thus, most probably, reliable government support. The renewable-energy production tax credit, which Congress threatens to cancel annually (and did cancel at the end of 2013),[486] has so far failed to provide the sustained and predictable incentive that the fracking revolution's story suggests is crucial. A diverse innovation ecosystem featuring players of various sizes and types will likely be critical for renewable energy—perhaps even more so than for fracking—because renewables have important

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481 *See supra* Part I.B.
482 *See supra* Part III.A.
483 *See supra* Part III.A.
484 *See supra* Part III.B–C.
485 *See supra* Part II.A.
486 *See* Powers, *supra* note 450.

applications in a variety of contexts ranging from the very localized and distributed to the mid-sized and highly centralized.[487] Infrastructure and government support will be equally important, and in this realm, renewables appear to be faring well: in relation to transmission, open-access requirements[488] and recent FERC directives for regional planning[489] are helping renewables overcome significant challenges.

Other aspects of the story behind the fracking revolution will likely find analogs in a revolution in the use of renewable energy. Shared information can facilitate the implementation of renewable-energy technologies in different geographies and climates as, for example, the precise placement of a wind turbine or solar panel can greatly affect its performance. Likewise, properly designed complementary assets could do more to spur innovation in renewables if states provided more effective recognition of the value of rights in wind or sunlight. Even the "negative lessons" from the oil and gas boom's harmful effects can be instructive. Renewable technologies can also have non-negligible negative impacts on their surroundings,[490] and policy adjustments over time will be needed to ensure that renewable technologies realize their full positive potential.

Similarly, lessons from the fracking revolution could facilitate development of energy technologies abroad. Other countries have not yet experienced the fracking boom seen in the United States, yet they are striving to replicate it. Stable, long-term support will be needed for substantial application of horizontal drilling and fracking abroad, as differences in both political and physical climates will not allow an international boom to emerge overnight. Lack of private ownership of mineral rights and of a preexisting phalanx of relatively nimble independent producers and service companies could impede replication of the fracking revolution in other countries. On the other hand, state ownership of minerals could allow for creative government partnerships with both small and large companies and could, as with FERC-provided funding for the GRI in the United States, give governments levers to encourage beneficial information sharing. Infrastructural challenges might be daunting,[491]

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[487] *See* Hannah J. Wiseman & Sara C. Bronin, *Community-Scale Renewable Energy*, 4 SAN DIEGO J. CLIMATE & ENERGY L. 165, 170–82 (2012–2013).

[488] *See supra* note 466 and accompanying text.

[489] *See supra* note 465 and accompanying text.

[490] Uma Outka, *The Renewable Energy Footprint*, 30 STAN. ENVTL. L.J. 241 (2011).

[491] *See supra* Part V.A.1.

but lessons from the United States' fracking revolution suggest that these challenges are some of the first that countries should seek to address. Finally, to avoid a backlash that could prevent new extraction technologies' from realizing their positive potential, foreign governments will likely need to identify risks and to adjust regulations to limit fracking's negative consequents.

An additional, more general implication of the fracking revolution's lesson about the value of diversity in innovation ecosystems is that a government seeking to facilitate socially beneficial innovation should be wary of casting its net too narrowly. The process of fostering major innovations tends to be too unpredictable and fortuitous to favor efforts to pick a small set of winners in advance. 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 technology area at the expense of another. As exemplified by the story behind the shale gas boom, revolutionary innovation can require decades of investment in technology areas or resources that were not originally viewed as significant. As these technologies are developing, so too must a supporting infrastructure that itself can take years to build and perfect. Under such circumstances, excessive focus on one technology area to the detriment of another could impoverish society by stunting the development of promising technological opportunities.

The fracking revolution's lessons regarding the potential importance of infrastructure and a diverse innovation ecosystem suggest not only that governments should commonly 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. 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 the story behind the fracking revolution shows, policymakers have a host of levers they can deploy.