WHERE THE SHALE GAS REVOLUTION CAME FROM

GOVERNMENT'S ROLE IN THE DEVELOPMENT OF HYDRAULIC FRACTURING IN SHALE

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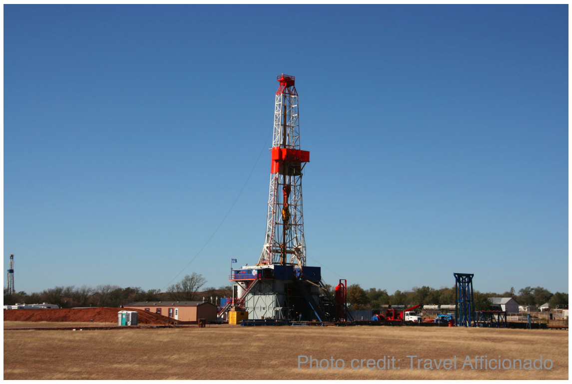
→ INTRODUCTION ←

America is in the midst of a natural gas boom, fueled principally by the development of technologies enabling the extraction of large gas reserves trapped in shale formations. Shales now produce over 25 percent of domestic natural gas resources, up from 2 percent in 2001.[1] The shale boom has also pushed natural gas's contribution to America's electricity generation portfolio from 20 percent to nearly 30 percent in the last few years alone.[2] Natural gas resources in shale, once thought to be unrecoverable and until this past decade prohibitively expensive to extract on a full commercial scale, are now accessible and abundant. The shale boom has expanded domestic energy production, pushed down wholesale electricity prices to record lows, and accelerated the retirement of America's aging coal plant fleet, significantly improving public health.[3] These advances were made possible by technological innovations resulting from a sustained partnership between the gas industry and the American federal government.



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In a series of investigations and interviews with historians, gas industry executives, engineers, and federal researchers, the Breakthrough Institute uncovered the historical role of the federal government in the development of cost-effective shale gas extraction technologies.[4] We consistently found that innovation and progress in the development of hydraulic fracturing and other key gas recovery technologies arose from public-private research and commercialization efforts. From basic science to applied R&D to technological demonstration to tax policy support and cost-sharing partnerships with private industry, federal programs proved essential to gas industry engineers in figuring out how to map, drill, and recover shale gas – and, most importantly, how to do it cost effectively.

In summary, federal investments and involvement in the development of shale gas extraction technologies spanned three decades and were comprised of:

- The Eastern Gas Shales Project, a series of public-private shale drilling demonstration projects in the 1970s;
- Collaboration with the Gas Research Institute (GRI), an industry research consortia that received partial funding and R&D oversight from the Federal Energy Regulatory Committee (FERC);

- Early shale fracturing and directional drilling technologies developed by the Energy Research & Development Administration (later the Department of Energy), the Bureau of Mines, and the Morgantown Energy Research Center (later the National Energy Technology Laboratory);

- The Section 29 production tax credit for unconventional gas, in effect from 1980-2002;

- Public subsidization and cost-sharing for demonstration projects, including the first successful multi-fracture horizontal drilling play in Wayne County, West Virginia in 1986, and Mitchell Energy's first horizontal well in the Texas Barnett shale in 1991;

- Three-dimensional microseismic imaging, a geologic mapping technology developed for applications in coal mines by Sandia National Laboratories.

These federal investments, coordinated in close concert with gas industry representatives, were predicated upon a single mission: the commercialization of shale gas extraction technology. As a result of these efforts carried out over the course of 30 years, shale gas went from inaccessible deposits locked in unfamiliar geologic formations to the fastest growing contributor to the nation's energy portfolio.

Shale Gas Development in the United States: A Timeline

1821: Natural gas is first extracted from shale in Fredonia, NY.

1970s: Domestic gas production on the decline; Morgantown Energy Research Center (MERC) initiates the Eastern Gas Shales Project.

1820 — 1950 — 1970 — 1980

1947: Hydraulic fracturing first used to extract natural gas from limestone.

1976: Two MERC engineers patent early technique for directional drilling in shale.

1977: DOE successfully demonstrates massive hydraulic fracturing in shale (MHF).

1980: Congress creates Section 29 production tax credit for unconventional gas (lasts until 2002).

1991: GRI subsidizes Mitchell Energy's first successful horizontal well in the Texas Barnett shale.

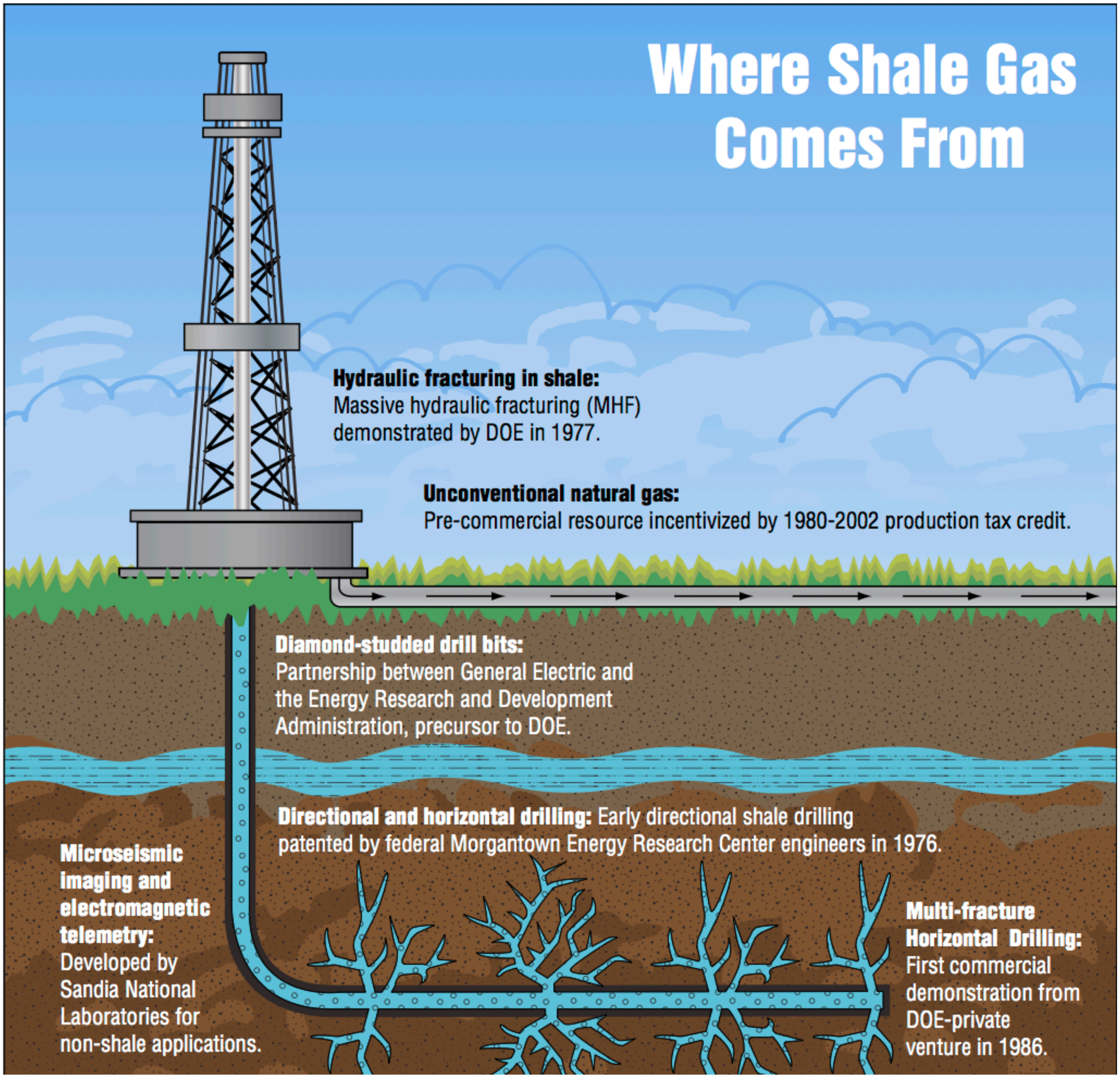
2000s: Natural gas generation grows faster than any other energy source; shale gas boom pushes prices to record lows.

1980 — 1985 — 1990 — 1995 — 2000 — 2005

1986: First successful multi-fracture horizontal well drilled by joint DOE-private venture in Wayne County, West Virginia.

1998: Mitchell Energy engineers achieve commercial shale gas extraction.

→ THE ROLE OF THE GOVERNMENT ←



→ HISTORY OF THE SHALE REVOLUTION ←

Before the Revolution

Natural gas was first extracted from shale in Fredonia, New York in the 1820s, several years before the breakthrough oil discoveries at wells in Titusville, New York.[5] But shale gas usage was limited to early and small-scale operations – it would not play a significant role in America's energy portfolio for another century and a half.

Today, shale gas is extracted via a process called hydraulic fracturing.[6] While fracturing has been used for natural gas extraction since the 1940s,[7] it wasn't until the 1970s and 1980s that efforts to apply the technique in shale deposits were developed. Shale formations have a peculiar geology of high porosity but low permeability. Unlike limestone or sandstone, shale's characteristics make it particularly difficult to fracture predictably. Conventional rotor drill bits and poor imaging technologies made reliable fracture tracking practically impossible. Significant basic research was needed to understand shale geology before technical applications could be fully commercialized to capture the natural gas resources locked inside.

As such, conventional fracturing techniques proved unsuccessful in shale. Engineers had neither the technology nor the knowledge base to cost effectively map shale expanses, drill horizontally in the formations, initiate fractures that were productive and predictable, and recover the gas resources locked in the formations. It is not surprising then that, while geologists had known since the 1820s that there were significant gas deposits in shale,[8] we didn't start to capture these resources until the late 20th century. Indeed, before the development of shale fracturing technologies, gas companies would drill past shale to get to sandstone deposits underneath.[9]

What is Hydraulic Fracturing?

Hydraulic fracturing, or "fracking," is a resource recovery technique used to extract natural gas stored in geologic formations. Used in limestone and sandstone gas deposits since the 1940s and in shales since the 1970s, fracking involves drilling through permeable rock expansions and pumping in a combination of water, sand, chemical lubricants, and "propants" to keep the induced fractures open for gas recovery.

An Industry In Decline Finds a New Partner

Conventional natural gas production in the United States began to decline in the early 1970s.[10] In a decade when both the Ford and Carter administrations were prioritizing fossil energy R&D during the oil crises, the natural gas industry reached out to federal research agencies for help in buffering domestic gas resource potential.[11] The industry and federal researchers had their eyes on unconventional resource bases that stood out of reach from contemporary drilling technologies, including coalbed methane deposits, "tight sands" natural gas, and shale gas.[12]

While Jimmy Carter is often pointed to as the president who initiated the energy push in response to the oil crises of the early seventies, it was Republican President Gerald Ford whose administration began a concerted federal effort to seek unconventional natural gas in response to shortages. In 1976, the Morgantown Energy Research Center (MERC, now the National Energy Technology Laboratory) and the Bureau of Mines (BOM) initiated the Eastern Gas Shales Project, which established a series of demonstration partnerships with universities and private gas companies in Pennsylvania and West Virginia. That same year, two MERC engineers - Joseph Pasini III and William K. Overby, Jr. – patented an early directional shale drilling technique that allowed operators to span larger radial expanses of shale deposits. These breakthroughs would later lead to horizontal well drilling in shale, which ultimately proved a much more cost effective method for recovering large stores of natural gas.[13]

Dan Steward, former Mitchell Energy Vice President

"In the seventies we started running out of gas, and that's when the DOE started looking for more. The DOE's [Eastern Gas Shales Project] determined there was a hell of a lot of gas in shales.

"We got the DOE and the GRI [Gas Research Institute] involved in the Barnett in the early 1990s. Mitchell hadn't wanted to get them involved because we were trying to understand it and didn't want competition for the Barnett until we had a handle on what we were doing. By the early 1990s, we had a good position, acceptable but lacking a knowledge base, and then Mitchell said 'Okay, I'm open to bringing in DOE and GRI' in 1991.

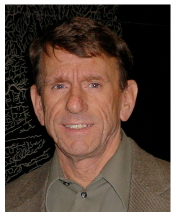
"Mitchell was selling his gas a dollar and a quarter over the spot price. Mitchell had the money to invest in R&D. So you could say that those pricing scenarios, and the [Section 29] tax credit, created the possibility for shale gas.

"DOE started it, and other people took the ball and ran with it. You cannot diminish DOE's involvement."

For the complete interview with Dan Steward, go to http://thebreakthrough.org/blog/2011/12/interview_with_dan_steward_for.shtml

A key early innovation came from a partnership between General Electric and the Energy Research and Development Administration (ERDA, a precursor to DOE) to develop advanced drill bits. Diamond-studded bits proved more effective at drilling through shale than conventional tools. ERDA originally sought to use the diamond technology for drilling in hot dry rocks for the agency's geothermal energy program, but the more successful application came when ERDA developed drill bits for shale drilling in collaboration with the gas industry.[14]

Terry Engelder, Penn State University Professor



"[The Eastern Gas Shales Project] helped expand the limits of gas shales production and increased understanding of production mechanisms. It is one of the great examples of value-added work led by the DOE.

"The government got it really right. In terms of a symbol of effective public-private venture, it's shale gas.

"The amount of money spent on R&D right now is sadly lacking. This [shale gas research] really took 20 to 30 to 40 years before it really worked. In terms of solar, it's going to be the same."

For the complete interview with Terry Engelder, go to http://thebreakthrough.org/blog/2012/01/terry_engelder_on_the_federal.shtml.

Federal researchers and engineers often worked very closely with natural gas companies in the development and refinement of shale gas recovery tools and techniques. The National Labs, including Sandia, Los Alamos, and Lawrence Livermore, contributed modeling, monitoring, and evaluation to the MERC-contracted demonstration projects. In 1979, the public-private efforts to drive shale gas and coalbed methane to market were formalized in the new Department of Energy's Commercialization Plan for Recovery of Natural Gas from Unconventional Sources.[15]

Because of shale's peculiar geology, new imaging technology was necessary to map shale deposits. Three-dimensional microseismic imaging, a technology developed by Sandia National Laboratories for work in coal mines, was serendipitously imported for application in shale gas drilling.[16] The new seismic tools and mapping software allowed drillers to visualize the shale formations and locate the natural fractures and unevenly-distributed gas deposits. Without microseismic, shale drillers were blind, and it is unlikely that either public or private fracturing R&D efforts could have proved fruitful without the critical imaging technology.[17]

In 1980, Congress passed the Windfall Profits Tax Act, which among other things created the Section 29 production tax credit for unconventional gas, providing an incentive of $0.50 per thousand cubic feet (Mcf) of natural gas produced from unconventional resources.[18] The tax credit expired in 2002, after Mitchell Energy had achieved commercial production from the

Barnett shale. Production of unconventional gas nearly quadrupled over this period, with the production tax credit vital to the growth and maturation of this advanced energy industry.[19]

Federal support proved essential in the early goings of the shale gas revolution. As Fred Julander, head of Julander Energy and member of the National Petroleum Council, notes, "The Department of Energy was there with research funding when no one else was interested and today we are all reaping the benefits. Early DOE R&D in tight gas sands, gas shales, and coalbed methane helped to catalyze the development of technologies that we [in the industry] are applying today."[20]

Alex Crawley, former Associate Director for Research, National Petroleum Technology Office

“After ERDA was formed the emphasis was on ‘what can we do to help energy production in this country’ during the embargo.

“All that technology coming together - massive hydraulic fracturing, diamond-studded drill bits, 3D seismic imaging, directional drilling - it wasn’t until the 1980s that it became economical enough to repeat it. [Before that,] they were drilling through shale to get to sandstone reservoirs.

“As far as shale is concerned, I don’t know that industry would ever have taken a look at it without the federal program, because it didn’t look like it had the porosity to be reachable. Government’s not going to step in and develop anything all the way through, but working with industry you have a different set of eyes. If you keep an open mind the government can become a real catalyst.”

For the complete interview with Alex Crawley, go to http://thebreakthrough.org/blog/2012/05/interview_with_alex_crawley_former_program_director_for_the_energy_research_and_development_administration

Mitchell Energy Cracks the Barnett

Most of the early R&D and demonstration work was done in the Devonian and Marcellus shales, large shale formations occupying portions of Pennsylvania, Ohio, Kentucky, and West Virginia.[21] But the final breakthroughs would come in the Barnett shale in northeast Texas. George Mitchell, a veteran of the Texas natural gas industry, wanted to apply the technologies developed in the Eastern United States to the Barnett.[22] He and other industry representatives spent much of the 1980s advocating for DOE fossil energy research, even as Congress attempted to zero out R&D budgets as the nation enjoyed low oil prices.[23] In the mean time, Mitchell Energy’s engineers and geologists performed considerable in-house R&D, working to scale hydraulic fracturing for commercial application in shale gas recovery.[24]

In 1986, a DOE/private venture first demonstrated a multi-stage horizontal fracture in the Devonian shale.[25] Commercial-scale hydraulic fracture recovery, however, would not come until after Mitchell Energy's team had finished work on refining the drilling processes and inputs. Here, again, the federal government would step in to aid the private sector.

In addition to innovating on top of platform technologies like MHF and directional drilling that were originally developed by the ERDA, MERC, DOE, and other federal agencies, Mitchell Energy benefitted from a direct and sustained partnership with the federal government. In the 1980s Mitchell relied on DOE mapping techniques and research to understand the complex geology of tight shale formations. In 1991, Mitchell partnered with DOE and GRI to develop tools that would effectively fracture formations in the Barnett shale, which now produces over 6 percent of all domestic natural gas.[26] GRI's microseismic imaging data proved particularly useful throughout the 1990s when Mitchell Energy would make the final key innovations credited with "cracking the Barnett."

Although unconventional gas production had been growing since the early 1980s, hydraulic fracturing technology had not been perfected or scaled to the point where full commercial deployment was competitive without subsidy. Shale gas production relied on the Section 29 production tax credit and on developers like Mitchell Energy charging a premium for gas resources. Mitchell Energy invested revenues in in-house R&D throughout the 1980s and 1990s.[27] Having successfully demonstrated multi-fracture horizontal well drilling techniques in the Barnett, engineers had to develop the optimal combination of inputs – water, sand, propants, chemical lubricants, etc. – to achieve maximum gas recovery at the lowest cost possible. In 1998, Mitchell Energy engineers, led by Nick Steinsberger, applied an innovative drilling technique called 'slick water fracturing' (or 'light sand fracking') that brought fracture job costs down to around $100,000, compared to between $250,000 and $300,000 for MHF projects.[28] This is widely considered a milestone that pushed shale gas into full commercial competitiveness.

Mitchell Energy was bought by Devon Energy in 2002 for $3.5 billion, the same year that the Section 29 production tax credit was allowed to expire.[29] The rest, as they say, is history.

→ FREQUENTLY ASKED QUESTIONS ←

If hydraulic fracturing was around in the 1940s, why did the government start investing in it in the 1970s?

Hydraulic fracturing was used in limestone and sandstone for decades before the onset of the shale revolution. Before the shale revolution, it was common knowledge that shale formations spread throughout the country contained plentiful stores of natural gas. But it wasn't until the 1970s, with the American gas industry suffering from declining production rates, that there were any significant attempts to apply the technology in shales. Early attempts proved challenging, and full-scale commercial shale fracturing would only be achieved after decades of public and private investments in new shale gas recovery technologies, including drilling, fracturing, and advanced mapping techniques.

Was this simply a case where the government introduced early iterations of the technology that were then perfected by private sector innovators?

While private gas companies, particularly Mitchell Energy, did provide substantial in-house R&D to the shale gas commercialization effort, federal programs were involved along every phase of the innovation pipeline. From early R&D (diamond-studded drill bits, microseismic imaging, directional drilling) to cost-sharing on demonstration projects (the Eastern Gas Shales Project, the subsidization of Mitchell Energy's first horizontal drill in the Barnett) to tax policy support for a pre-commercial industry (the 1980-2002 Section 29 production tax credit for unconventional gas resources), federal agencies and policies acted over 25 years to maximize the effect of shale gas research and commercialization.

Who's to say that the private sector wouldn't have developed the tools they needed faster and at lower cost than federal researchers?

It's clear that government investment and research worked to drive innovations and cost declines in shale gas extraction technologies, but one could construct a counterfactual argument that the private sector would have achieved these gains without any public support. But history puts this counterfactual to the test: there are plenty of countries with sizable shale deposits but without America's strong public innovation system – including Russia, China, Poland, South Africa, Britain, and others – whose active oil and gas industries did not make congruent investments in shale fracturing technologies. It was the United States that first cracked the shale gas challenge through decades of research and commercialization; shale fracturing operations in other countries are only now getting off the ground.

Technologies like diamond-studded drill bits and microseismic imaging were developed by federal agencies for non-shale applications, demonstrating the clear and present value of publicly-funded basic research. The initial shale fracturing research and demonstration projects were initiated by the federal Morgantown Energy Research Center, and the bulk of private sector R&D took place within the Gas Research Institute, a gas industry research consortia funded partially by a FERC-approved surcharge on natural gas pipelines whose research budgets were subject to federal approval.

Because private companies have difficulty monetizing and capturing all the benefits of energy technology research, it is consistently the case that federal coordination and investment is required to drive high-level technological innovation in the energy sector. As documented in the Breakthrough Institute's 2010 report "Where Good Technologies Come From," the American federal government has historically played a leading role in the development a broad range of innovative technologies, including microchips, jet turbines, nuclear power reactors, and the Internet.[30]

The gas industry itself has spoken on behalf of federal research efforts. "The DOE started it, and other people took the ball and ran with it," said Mitchell Energy's former Vice President Dan Steward. "You cannot diminish DOE's involvement."

→ NOTES AND CITATIONS ←

[1] See *Annual Energy Outlook 2012*, United States Energy Information Administration, released January 23, 2012, http://www.eia.gov/forecasts/aeo/er/pdf/0383er(2012).pdf.

[2] See *Short Term Energy Outlook*, United States Energy Information Administration, released May 2012, http://www.eia.gov/forecasts/steo/pdf/steo_full.pdf.

[3] Ibid. See also: Alex Trembath, "Have US Emissions Peaked?" Breakthrough Institute, April 10, 2012, http://thebreakthrough.org/blog/2012/04/have_us_emissions_peaked.shtml.

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[9] Alex Crawley, former Associate Director of Fossil Energy Research at the US Department of Energy. Telephone interview by Alex Trembath on January 31, 2012.

[10] For monthly figures on American natural gas production, see "Natural Gas Gross Withdrawals and Production," US Energy Information Administration (published monthly), accessed May 8, 2012. http://www.eia.gov/dnav/ng/ng_prod_sum_dcu_NUS_m.htm.

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[12] Terry Engelder, Professor at Penn State University. Telephone interview by Michael Shellenberger on November 25, 2011.

[13] See "Shale Gas: Applying Technology to Solve America's Energy Challenges," US National Energy Technology Laboratory (NETL), http://www.netl.doe.gov/technologies/oil-gas/publications/brochures/Shale_Gas_March_2011.pdf. See also "A Century of Innovation," National Energy Technology Laboratory (NETL), 2010, http://www.netl.doe.gov/newsroom/100yr/NETL-A_Century_of_Innovation.pdf.

[14] Interview with Alex Crawley, op cit. note 9. See also Robert W. Fri, "From Energy Wish Lists to Technological Realities," *Issues in Science and Technology*, Fall 2006, http://www.issues.org/23.1/fri.html.

[15] MERC, op cit. note 11.

[16] See "Energy Research at DOE: Was It Worth It? Energy Efficiency and Fossil Energy Research 1978 to 2000," Committee on Benefits of DOE R&D on Energy Efficiency and Fossil Energy, Board of Energy and Environmental Systems, Division on Engineering and Physical Sciences, National Research Council, 2001, http://www.nap.edu/openbook.php?isbn=0309074487.

[17] Interview with Alex Crawley, op cit. note 9.

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[22] Daniel Yergin, “The Natural Gas Revolution,” from*The Quest: Energy Security and the Remaking of the Modern World*, published by the Penguin Group, New York, NY, 2011.

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[27] Ibid.

[28] Nick Steinsberger, former managing engineer for Mitchell Energy. Telephone interview by Alex Trembath on December 12, 2011.

[29] Yergin, op cit. note 22.

[30] Jesse Jenkins, Devon Swezey, Yael Borofsky, Helen Aki, Zachary Arnold, Genevieve Bennett, Chris Knight, Ashley Lin, Teryn Norris, Taj Walton, and Adam Zemel, “Where Good Technologies Come From: Case Studies in American Innovation,” Breakthrough Institute, December 2010, http://thebreakthrough.org/blog/Case%20Studies%20in%20American%20Innovation%20report.pdf.