American Energy Innovation Council

CASE STUDIES ON THE GOVERNMENT'S ROLE IN ENERGY TECHNOLOGY INNOVATION

Unconventional Gas Exploration & Production

By Jason Burwen and Jane Flegal | March 2013

Introduction

The outlook for North America's natural gas supply has improved dramatically in recent years as horizontal drilling and hydraulic fracturing technologies have made it possible to commercially develop unconventional gas reserves, particularly shale gas reserves. These gas basins are located in diverse geographical areas, spanning at least 31 states in the continental United States. Whereas domestic production was thought to be on a declining trajectory as recently as 2007, the rapid increase in production from gas shales has driven overall production increases every year since then.[1] Although precise accounting is not available, shale gas production alone was estimated to directly account for nearly $30 billion of economic activity and nearly 150,000 jobs in 2010.[2] With new discoveries increasing proven unconventional gas reserves each year, the United States is now believed to have sufficient gas resources to meet domestic demand for many years at current rates of consumption.[3]

Unconventional Gas, Horizontal Drilling, and Hydraulic Fracturing

The term "unconventional gas" refers to the method of extraction used for natural gas. Conventional gas consists of drilling conventional vertical wells through hard rock to get to trapped subterranean reservoirs of natural gas. Unconventional gas, on the other hand, is impounded in porous, low-permeability features that act like a "sponge," such as shale rock, sandstone, and coal seams. In order to extract unconventional gas economically, well operators make use of a combination of horizontal drilling and hydraulic fracturing.

Horizontal drilling begins with a vertical shaft, like a typical well. Once it approaches the depth of the targeted oil or gas reservoir, the shaft bears off at an arc, so it can intersect the reservoir at

Figure 1: **Known Unconventional Gas Resources in the Continental United States**[4]

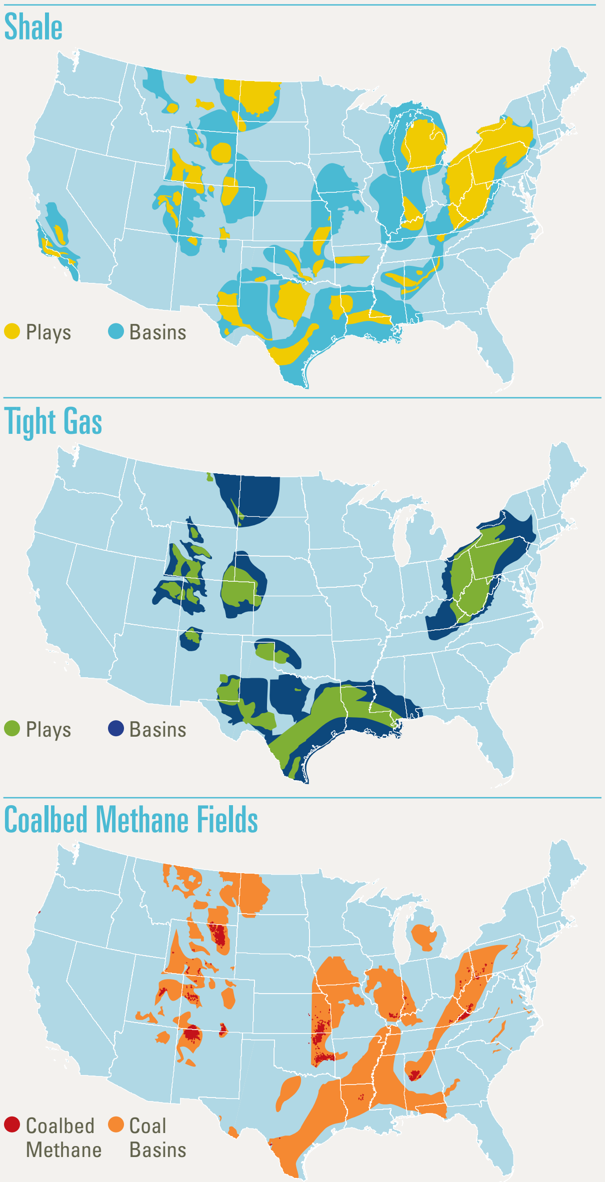
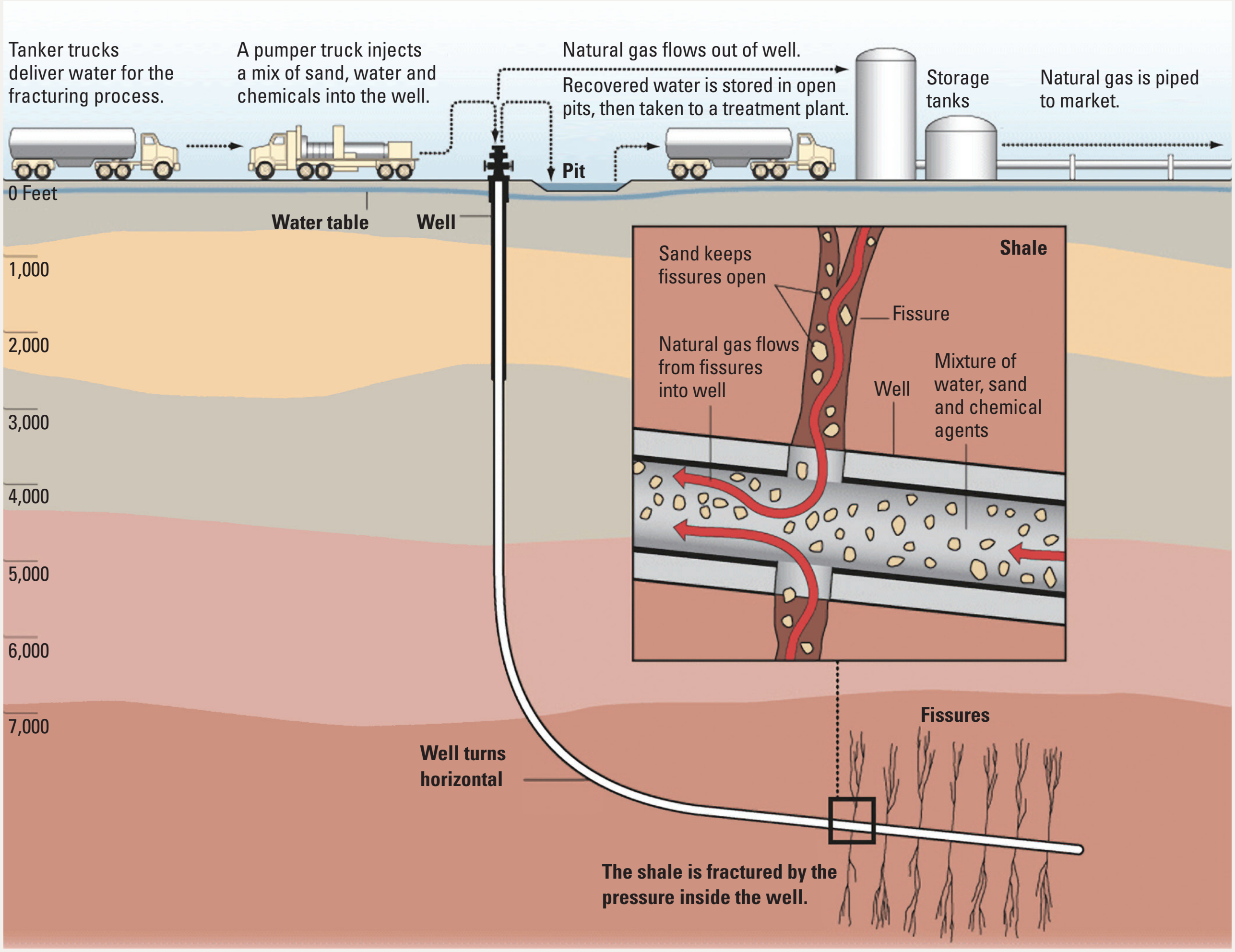


Figure 2: **Unconventional Gas Production Methods**[5]



Graphic by Al Greenberg/ProPublica

a near-horizontal angle. It continues horizontally, through the reservoir, until the desired length is reached. Horizontal wells are designed to dramatically increase the production of a well by offering greater contact with the productive layer of a reservoir. While the construction of a directional well often costs two to three times as much as a conventional well, initial production is often three to four times that of a conventional well.

Hydraulic fracturing—colloquially called "fracking"—consists of injecting millions of gallons of water, proppant (e.g., granules of sand, ceramic, etc), and chemicals at high pressure into a shale or sandstone formation. The build-up in pressure causes the formation to fracture, and the proppant fills the fractures to keep them from resealing. This allows the natural gas impounded in the formation to rush into the well for extraction. Most wells are fractured repeatedly over the course of well operation, as the fractures reseal naturally over time.

Development of Unconventional Gas Technology Development

While the first recorded horizontal well was drilled in 1929 and the first recorded hydraulic fracturing was undertaken in 1947,[6] unconventional gas production through these combined techniques became commonplace only in the 1990s after years of federal support and further innovations.[7] When federal efforts to improve unconventional gas production were initiated in the mid-1970s, the higher costs and risks of horizontal drilling discouraged investment by many private companies, and horizontal wells were only considered financially advantageous in reservoirs characterized by low permeability or where water or gas intrusion was a serious concern; moreover, the industry consensus was that deep shale formations were not economically viable.[8, 9] Coalbed methane was jokingly referred to as "moonbeam gas," due to the perceived impossibility of economic extraction.[10]

> "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 are applying today."
>
> —Fred Julander, Julander Energy and past President of the Colorado Oil & Gas Association[11]

While the private sector has driven the continuous improvements and breakthroughs in exploration and production technologies for unconventional natural gas, the federal government has substantively aided this effort in several ways: resource mapping; coordinating and complementing industry efforts; basic research and development; and tax credits for unconventional gas.

The federal government mapped shale gas resources and funded experimental wells, undertaking research no single firm could and lowering the eventual costs and risks of shale gas exploration.

In 1976, in the aftermath of the OPEC oil embargo and in light of declining domestic gas production, Congress funded the Unconventional Gas Research Program to help develop the U.S. domestic natural gas resource base. The Unconventional Gas Research Program included the Eastern Gas Shales Project (EGSP),[12] which focused on three key issues: developing a resource inventory of the Devonian shales in three basins;[13] determining the recoverable reserves of Devonian shale gas; and determining the most effective technologies for extracting this gas at least cost. The EGSP was funded from 1976–1992, with its annual budget peaking in 1979 at $18 million ($47 million in 2011 dollars); total expenditures over the lifetime of the program were approximately $92 million ($185 million in 2011 dollars).[14]

Prior to EGSP, there was considerable uncertainty about the magnitude of the potential shale gas resource that precluded industry from knowing where to drill. Furthermore, nothing was known about the geochemistry of gas shales; without cores, logs and maps of the shale gas depositional environment and tectonic activity, the knowledge base was lacking for exploration into this high risk, limited economic resource. Finally, technology for shale gas recovery was crude, and the benefits of costly horizontal drilling in gas shales had never been investigated.

The early years of the EGSP focused on resolving the above questions and on cost-sharing arrangements with oil and gas operators for demonstration wells. 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.[15] In addition, the EGSP produced a number of maps, technical reports, evaluations, and cross sections relevant for unconventional shale gas exploration and production, synthesizing disparate data related to resource base assessments.

> “The magnitude and scope of the DOE program were important because most of the firms involved in gas shale recovery at that time were small independents who had little or no research budgets. These producers could not have mounted R&D on the scale and the scope of the DOE effort, nor could they have continued DOE’s level of effort during the late 1970s and 1980s. Thus, it is likely that the DOE effort did not displace or substitute for R&D that would have occurred otherwise in the private sector.”
>
> —Roger H. Bezdek, President of *Oil & Gas Investor*[16]

Importantly, the EGSP was designed as collaboration with industry from its inception, which encouraged private investment in technological development by facilitating cost-sharing and risk-sharing between the government and industry.[17] EGSP research was managed by the U.S. Energy Research and Development Administration’s (the predecessor to the Department of Energy) Morgantown Energy Technology Center[18] and involved more than 40 partners from industry, universities, and research institutions.[19] Work to inventory the unconventional shale gas resource base was completed principally through contracts with state geological surveys and universities, with results compiled by the United States Geological Survey (USGS). Descriptions of the resource base were contracted to universities, research institutions, and industry. Personnel from the EGSP would later be hired by private industry, taking their skills and knowledge with them.[20]

The federal government enabled greater public-private partnership in unconventional gas R&D, coordinating basic and applied research as well as accelerating technology transfer in the industry.

At the same time that DOE initiated the EGSP, the Federal Energy Regulatory Commission approved a charge on interstate gas sales in 1976 to fund gas technology R&D.[21] Funds primarily supported the Gas Research Institute (GRI), an industry collaborative research organization. GRI’s early budget was approximately $40 million per year, growing to $200 million per year in the 1990s.[22, 23]

DOE coordinated extensively with GRI. 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.[24] DOE representatives participated on guidance committees related to GRI research, and the two organizations conducted semiannual meetings to discuss high level planning direction and to ensure that research was effectively coordinated. For example, GRI switched its initial focus from coal gasification to unconventional gas production, based on DOE’s prior work and guidance.[25] Both groups hired external experts and involved industry partners to perform R&D and help commercialize products.

Public-private partnership was crucial not only so that industry efforts were aligned with greater strategic DOE goals, but also so that industry knowledge could update and inform government priorities. For example, GRI’s industry board, which included Mitchell Energy, convinced DOE to refocus away from Eastern Gas Shales to first Michigan’s Antrim shales and then Texas’ Barnett shales[26]—that latter of which would end up as the site where the shale gas revolution took off. Furthermore, public-private partnership helped ensure continuity of R&D projects; as Congress reduced federal funding for unconventional gas research in the early 1990s, industry partners maintained numerous R&D projects.[27]

Moreover, the DOE partnership with GRI assisted technology diffusion. Major companies in the industry tend to guard knowledge of their own innovations as competitive advantages, and smaller operators often lack budgets to initiate significant R&D. By partnering federal support with GRI's research, the partnership required full publication of findings and required all industry partners involved in research to give up intellectual property claims to their findings. Moreover, FERC made GRI indifferent to royalties by subtracting any royalties from FERC funding; this ensured that GRI focused on technology diffusion as much as possible, rather than support itself from licensing income.[28] As a result, the public-private partnership was instrumental in catalyzing technology transfer within the industry.

Federally-funded research, development, and demonstration made several significant contributions to gas technology innovation at a time when private R&D was low and risks to industry high.

Starting in the early 1980s, major oil and gas companies began to decrease their research and development spending, driven in large part by a decision to "buy versus build" new technology.[29] Federally-funded R&D in unconventional gas therefore became a critical driver of new developments.

The federal government's funding of experimental demonstration wells was key. In the late 1970s and early 1980s, DOE stimulated experimental work on massive hydraulic fracturing methods by providing matching funds for private industry demonstration wells. In 1986, DOE collaborated with industry to achieve the first truly horizontal Devonian shale well in the Appalachian Basin.[30] Through the early 1990s, DOE and GRI worked with several companies to complete additional wells containing multiple hydraulically fractured zones; among these collaborations was Mitchell Energy's famous first horizontal well in the Barnett Shale.[31] These efforts were the first demonstrations of multiple-fracture horizontal drilling method in gas shales that would become the norm for all shale gas recovery. Mitchell Energy built on this demonstration and new knowledge by investing substantially in R&D. Innovating on findings from earlier massive hydraulic fracturing demonstrations, Mitchell eventually developed slickwater fracturing methods in 1998, the key that would drive down costs enough to make shale gas economical.[32]

> "They [DOE] did a hell of a lot of work, and I can't give them enough credit for that. DOE started it, and other people took the ball and ran with it. You cannot diminish DOE's involvement."
>
> —Dan Steward, former Vice President of Mitchell Energy[33]

Federally-funded developments in microseismic mapping were also significant. Microseismic mapping is a method by which well operators detect and measure faint at the at the base of wells deep underground to generate an image of a particular shale or sandstone formation's fractures; this mapping allows for lower drilling risks, higher well productivity, and lower overall costs. Several national laboratories accumulated expertise with microseismic mapping, due to involvement in geothermal, mining, and military applications and access to cutting-edge computing facilities.[34]

As part of the Unconventional Gas Program, the federal government funded several experimental wells in Colorado (called the Multiwell Experiment (MWX) and later called the M-Site). Using these wells, Sandia National Laboratory led a team that developed and demonstrated the techniques of real-time microseismic mapping for hydraulic fracturing and gas production.[35] While Sandia led initial efforts at microseismic fracture mapping in 1985 as part of a partnership with GRI, the Sandia-led team only successfully validated real-time microseismic fracture mapping in the mid-1990s[36]—aided by advances in measurement-while-drilling technologies previously developed in partnership with industry. These microseismic mapping techniques were rapidly commercialized and improved upon thereafter, and one of Sandia's prominent microseismic research scientists[37] moved into the private sector.[38]

> "[Microseismic monitoring], which has now been applied to tens of thousands of fracture treatments, and which is now itself a multi-million dollar industry, has allowed engineers to greatly improve hydraulic fracturing and well completion practices. The development of microseismic monitoring of hydraulic fracture treatments was clearly enabled by the Department of Energy funded research that proved its viability."
>
> —Dan Hill, Head of the Petroleum Engineering Department at Texas A&M[39]

In addition to these particularly significant contributions, DOE and the national laboratories provided a steady stream of contributions that incrementally advanced unconventional gas production. For example, as part of its geothermal energy research, Sandia Laboratory oversaw improvement of polycrystalline diamond compact (PDC) drill bits to penetrate hard rock. PDC drill bits are made by coating drill cutters with graphite powder and sintering them under extreme pressures; the combination of heat and pressure converts the graphite to a millimeter-wide layer of synthetic diamond, allowing the drill bit to cut harder rock, drill faster, and last longer. Sandia Laboratory engineers partnered with General Electric to resolving outstanding challenges with PDC material behavior, which included development of laboratory test procedures and computer models of drill bit performance.[40] Results from these laboratory tests and Sandia's computer modeling of drill bit performance, as well as further industry collaborations, spurred enormous applied research and development by private industry.[41] Despite being developed originally for geothermal energy applications, PDC drill bits came to be used by widely in the 2000s for unconventional oil and gas well drilling, accounting for as much as 60% of all drilled footage in 2005.[42] Similarly, DOE funded the invention of mud-pulse telemetry in the 1970s, the forerunner of many measurement-while-drilling technologies.[43] Other contributions include earlier horizontal drilling methods,[44] advances in downhole telemetry,[45] advances in coiled tubing for microhole efforts,[46] and a variety of other geological mapping efforts.[47]

Federal funding for gas R&D declined as unconventional gas economics improved and private sector production increased starting in the late 1990s. DOE funds for gas R&D ramped down precipitously from $117 million in 1997 to $44 million in 2001 and continuing to $12 million in 2007.[48]

Federal subsidies to unconventional gas made incremental reductions to extraction costs; while initially encouraging support at the margin, subsidies catalyzed the impact of rising gas prices on new exploration and innovation.

The Windfall Profits Tax Act of 1980 established a production tax credit for natural gas from unconventional resources.[49] The value of the credit was fixed at $0.52 per thousand cubic feet for gas from tight sands, equal to roughly one quarter of prevailing gas prices at the time.[50] For shale gas and coal-bed methane, the value of the credit was calculated by a formula based on oil prices and rose from zero in 1980 to $0.96 per thousand cubic feet in 1991, a value equal to nearly half of prevailing gas prices.[51] The Section 29 credit expired in 1992, and covered production finally ended in 2002. The Section 29 credit led to a more than doubling in production of unconventional gas from 1980 to 2002,[52] as well as innovations in drilling and completion technology,[53] despite restricted market access from lack of pipelines.[54] The credit stimulated production primarily from coal-bed methane and tight sands resources, where hydraulic fracturing was initially not as critical for economical well production as in later shale plays.[55]

The creation of production-based credits opened up a new domain of financing available for gas well operations. Since many small operators did not have substantial enough liabilities to take advantage of tax credits, they effectively "sold" their credits to larger firms in tax equity financing transactions. While the level of tax equity investment was modest, nonetheless Section 29 credits generated more investor interest and leveraged more private dollars in unconventional gas than existed previously.[56,57]

Perhaps more importantly, the credit stimulated industry to drill more wells and collect more data, contributing to applied knowledge of well operators. This learning-by-doing drove incremental improvements in technology, finding rates, and well productivities, thereby keeping unconventional gas resources economic even following the expiration of the Section 29 tax credits in 1992.[58]

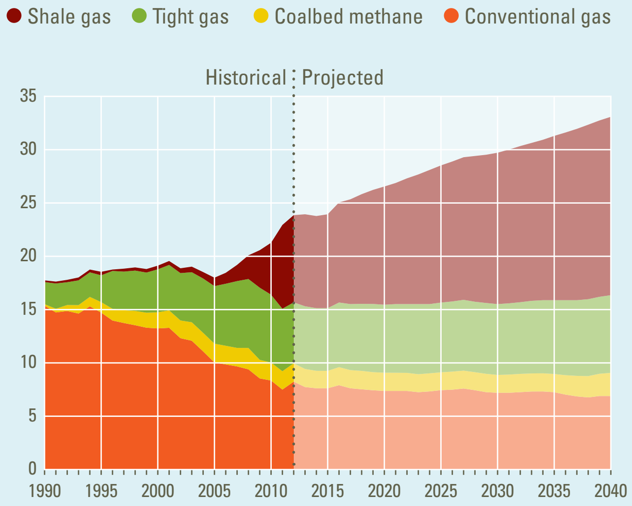
Overall, these efforts catalyzed developments that would have taken at least a decade to come to fruition.[59] As gas prices rose in the early 2000s, the economics of unconventional gas production shifted significantly, drawing new operators into the field and rapidly increasing well drilling. The combination of technological innovation and promotional policies in the previous two decades enabled a swift and dramatic response by industry. In turn, this increase in drilling activity and industry innovations revealed an even larger resource base than previously thought. Since 2000, proven natural gas reserves have increased over 70%, almost entirely due to shale gas resources.[60,61] Natural gas-fired power plants are projected to account for over 60% of new electric capacity additions between 2011 and 2035, in large part owing to the sustained low gas prices expected from continued unconventional gas production.[62]

The US is now expected to become a net exporter of natural gas in the next decade. Moreover, many of the shale formations that are being considered for natural gas development also contain oil; as a result, technological advances in shale gas have also greatly improved the likelihood of economically extracting oil from shale oil reserves.

At recent rates of production, shale gas production alone is roughly estimated to bring on the order of $100 billion of gains to consumers each year.[64] Government expenditures on unconventional gas R&D between 1976 and 1992 are estimated at $220 million ($473 million in 2011 dollars).[65] Although total Section 29 tax credit expenditures associated with unconventional gas have not been quantified,[66] Section 29 credits for unconventional gas have been estimated at $6 billion ($10 billion in 2011 dollars) between 1985 and 1991,[67] and other reports have estimated total expenditures perhaps twice that amount.[68] Even presuming tax credits cost substantially more than these estimates, the economic benefits of unconventional gas have repaid many times over the public investments that enabled and accelerated unconventional gas technological development.

Figure 3: **Production of Natural Gas by Source**[63]

(Trillions of cubic feet)



Lessons Learned

One lesson from the history of unconventional gas is that the federal government does not supplant private sector innovation, but rather lowers risks to private sector innovation and provides complementary inputs. Determined, risk-taking independents like Mitchell Energy drove innovation, and these private firms' actions have been well-chronicled.[69] However, the federal government's basic research was critical, since private sector R&D funds were declining and private firms could not take on the risks of ongoing, unproductive exploration using experimental methods. The federal government's research and development programs, which included particular technology demonstrations, both lowered exploration risks to industry and demonstrated the market potential of unconventional gas. Public-private partnerships were critical for ensuring complementarities and effective direction of R&D efforts, as well as speeding up diffusion of new research findings and technologies. While the private sector would drive applied R&D going forward, on occasion applied R&D from the federal government would make significant contributions and spur more innovation. Finally, new economic incentives from the federal government increased learning-by-doing and opened up a new pool

> "…the history of unconventional gas also provides a rich set of 'lessons learned.' These 'lessons' demonstrate that combining a well managed joint government/industry R&D technology program with performance-based incentives for early application of new technology can be highly successful, providing significant economic benefits to the U.S. economy."
>
> —Vello A. Kuuskraa, President of Advanced Resources International[70]

of private investment capital. As a result, government efforts greatly quickened the pace of private sector discovery and innovation.

A critical lesson is that the federal government undertook ultimately important basic R&D without being able to predict the full scope of its applications, and technologies developed in one area transferred to other domains. Although basic research carried out by the federal government created the geological and technical understanding to be able to effectively exploit unconventional gas resources, government scientists and engineers at the time could not predict the applications of its research. For example, a 1978 report commissioned by the Department of Energy did not consider gas in deep shale formations to be recoverable,[71] and much of the R&D that would lead to deep gas shales exploitation came from experiments in coal-bed methane and tight sands formations. Similarly, the antecedents of real-time microseismic mapping derived from mining and military R&D, and the development of PDC drill bits was originally intended for geothermal energy development.

Moreover, success was only evident in retrospect, as years or decades passed before the benefits of some technological advances were fully realized. Long time lags between proof-of-concept and commercialization are not uncommon in capital-intensive industries. In a 2007 report, the National Petroleum Council states, "Commercializing technology in the oil and gas market is costly and time-consuming; an average of 16 years passes from concept to widespread commercial adaption."[72] Technology consultancies estimate that new exploration and production technologies on average take over 20 years to reach commcericalization.[73] For example, although hydraulic fracturing was known since 1947, massive hydraulic fracturing techniques were only first explored in the late 1970s and early 1980s by DOE-funded efforts, and it wasn't until 1998 that Mitchell Energy successfully developed slickwater fracturing. Although major contributions by the government are now seen as substantial or positive, an observer in the mid-1980s or early 1990s might have concluded that government efforts were unproductive or even wasteful. Energy technology innovation is inherently uncertain, and aiming for game-changing breakthroughs requires a long-term perspective.

Innovation does not occur on a linear path. In the history of the federal government and unconventional gas development, many threads of effort came together from sometimes unexpected sources over a period of decades before resulting in identifiable successes. Government support for R&D should not simply be predicated on a near-horizon, A-to-B mindset if it is to support major energy technology breakthroughs and energy market transformations. Rather, as seen in the case of unconventional gas, government contributions to energy technology innovation occur at the often unexpected intersection of a diverse array of R&D efforts over longer periods of time.

Acknowledgments

The authors would like to thank the following interviewees for their contributions to this paper:

Vello A. Kuuskraa, President, Advances Resources International, Inc.

Ron Edelstein, Director of Government and Regulatory Relations, Gas Technology Institute

Kent Perry, Vice President of Onshore Programs, Research Partnership to Secure Energy for America

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