Shale Gas: *Applying Technology to Solve America's Energy Challenges*

The United States enjoys a rich complement of natural resources, including substantial quantities of fossil fuels—crude oil, coal, and natural gas. These energy sources have helped to fuel our Nation's growth and development for the past two hundred years.

The presence of natural gas—primarily methane—in the shale layers of sedimentary rock formations that were deposited in ancient seas has been recognized for many years. The difficulty in extracting the gas from these rocks has meant that oil and gas companies have historically chosen to tap the more permeable sandstone or limestone layers which give up their gas more easily.

Shale gas well on a Pennsylvania farm. (Photos courtesy of Range Resources)

But American ingenuity and steady research have led to new ways to extract gas from shales, making hundreds of trillions of cubic feet of gas technically recoverable where they once were not.

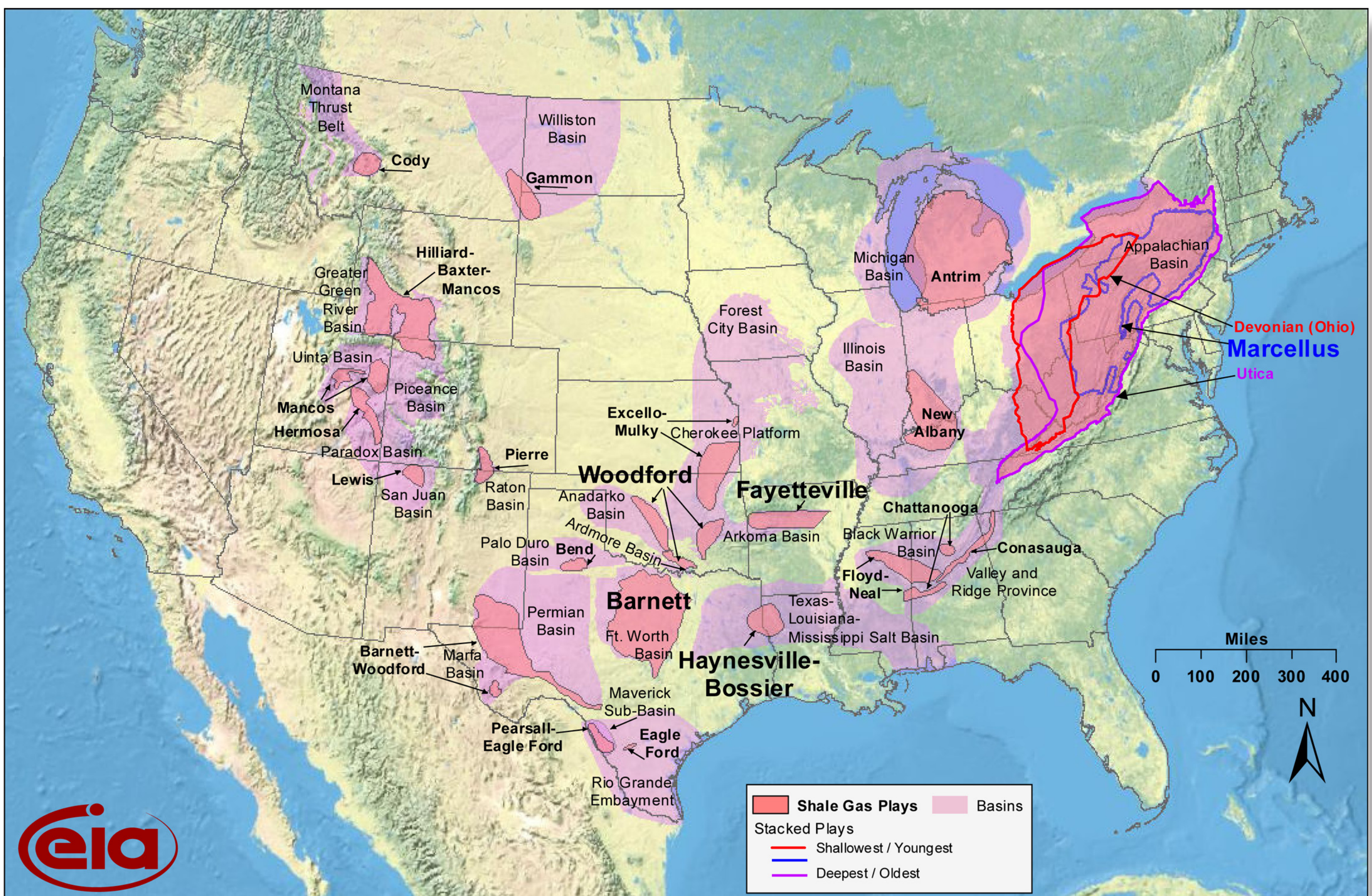
New technologies are also being applied to make certain that the process of drilling for this valuable resource minimizes environmental impacts.

U.S. DEPARTMENT OF ENERGY | NETL

Barnett shale well at urban location (Courtesy of Chesapeake Energy)

Fayetteville shale well (Courtesy of Southwestern Energy)

This resource's availability to the American people could not have come at a better time. The calls for reducing our reliance on foreign energy supplies, for reducing our contribution of carbon dioxide to the atmosphere, and for increasing economic growth and wealth creation, can all be met, at least in part, by the development of shale gas. The U.S. Department of Energy (DOE), through the National Energy Technology Laboratory (NETL), has played a historic role in helping to advance the technology that is making shale gas production possible.



This map, available from the U.S. Energy Information Administration (EIA) at http://www.eia.doe.gov, shows the location and extent of the major shale plays (e.g., Marcellus shale) and the sedimentary basins (regions with thick layers of sedimentary rock containing fossil fuels) where these shale plays are found.

The Resource

Where shale gas comes from

About 360–415 million years ago, during the Devonian Period of Earth's history, the thick shales from which we are now producing natural gas were being deposited as fine silt and clay particles at the bottom of relatively enclosed bodies of water. At roughly the same time, primitive plants were forming forests on land and the first amphibians were making an appearance. Some of the methane that formed from the organic matter buried with the sediments escaped into sandy rock layers adjacent to the shales, forming conventional accumulations of natural gas which were relatively easy to extract. But some of it remained locked in the tight, low permeability shale layers.

This map of what geologists believe the land looked like 385 million years ago (during the Middle Devonian period) shows the outlines of today's states, and the bodies of water that created the Michigan, Appalachian, and Illinois basins can be seen. (Courtesy Prof. Ron Blakey, Northern Arizona University)

History of development

The shale gas timeline includes a number of important milestones:

Photo credit Drake Well Museum

1821 – First U.S. commercial natural gas well in Fredonia, New York, produces gas from shale.

1859 – Edwin Drake demonstrates that oil can be produced in large volumes, launching the U.S. oil industry.

1860s to 1920s – Natural gas, including gas produced from shallow, low pressure, fractured shales in the Appalachian and Illinois basins, is limited to use in cities close to producing fields.

Photo credit Library of Congress

1930s – Technology developed to lay large diameter pipelines makes transmission of large volumes of gas from midcontinent and southeastern oil fields to northeastern cities possible; the natural gas industry grows exponentially.

Photo credit Ohio Historical Society

Photo credit Pennwell

Late 1940s – Hydraulic fracturing first used to stimulate oil and gas wells. The first hydraulic fracturing treatment (not shown here) was pumped in 1947 on a gas well operated by Pan American Petroleum Corporation in Grant County, Kansas.

Early 1970s – Development of downhole motors, a key component of directional drilling technology, accelerates. Directional drilling capabilities continue to advance for the next three decades.

Late 1970s and early 1980s – Fear that U.S. natural gas resources are dwindling prompts federally sponsored research to develop methods to estimate the volume of gas in "unconventional natural gas reservoirs" such as gas shales, tight sandstones and coal seams, and to improve ways to extract the gas from such rocks. Deeper buried shales, such as the Barnett in Texas and Marcellus in Pennsylvania, are known but believed to have essentially zero permeability and thus are not considered economic.

1980s to early 1990s – Mitchell Energy combines larger fracture designs, rigorous reservoir characterization, horizontal drilling, and lower cost approaches to hydraulic fracturing to make the Barnett Shale economic.

2003 to 2004 – Gas production from the Barnett Shale play overtakes the level of shallow shale gas production from historic shale plays like the Appalachian Ohio Shale and Michigan Basin Antrim plays. About 2 billion cubic feet (Bcf) of gas per day are produced from U.S. shales.

Photo credit Pennwell

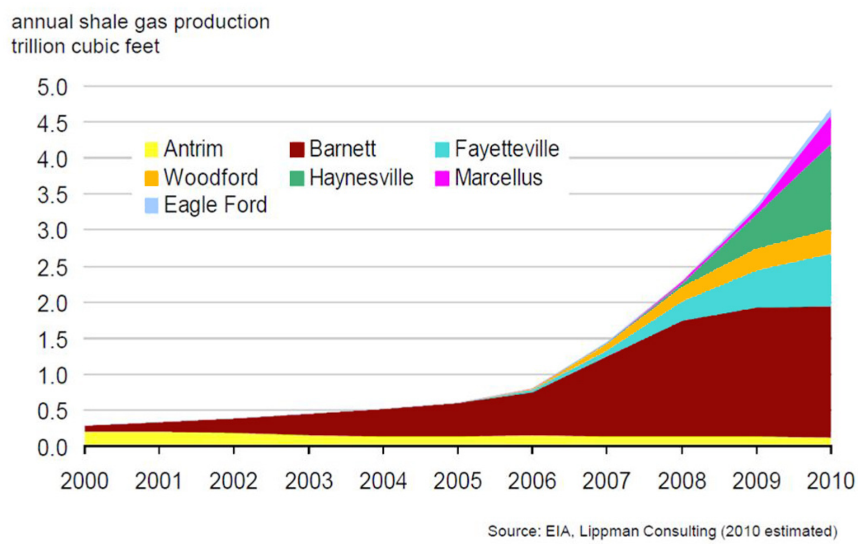
2005 to 2010 – Gas production from Barnett Shale grows to about 5 Bcf per day. Development of other major shale plays begins in other major basins.

2010 – The Marcellus shale underlies a significant portion of the mid-Atlantic/NE region—close to East Coast metropolitan natural gas demand centers—and is thought to contain nearly half of the technically recoverable shale gas resource.

Production trend

Shale gas production continues to increase. In 2009 it amounted to more than 8 Bcf per day, or about 14 % of the total volume of dry natural gas produced in the United States and about 12% of the natural gas consumed in the United States. Production from the Barnett Shale has leveled off, but volumes of gas from the Marcellus, Haynesville, Fayetteville and Woodford shales are growing as more wells are drilled in these plays and as other emerging plays are developed. The EIA projects that the shale gas share of U.S. natural gas production will continue to grow, reaching 45% of the total volume of gas produced in the United States by 2035.

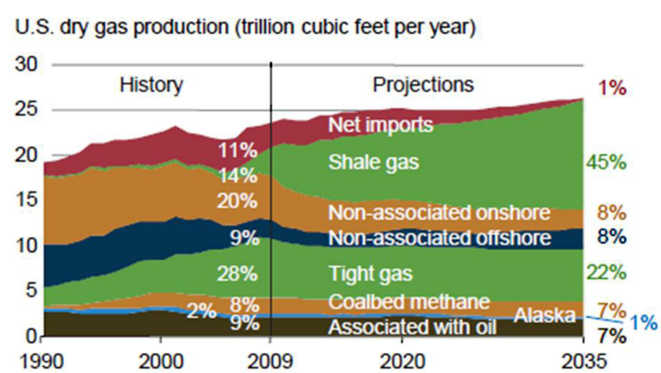
Core from organic Devonian shale formation



What it means for us

The EIA projects that there are 827 trillion cubic feet (Tcf) of natural gas that are recoverable from U.S. shales using currently available technology. The United States currently consumes about 23 Tcf per year, of which we produce about 20 Tcf and import the rest, so the shale gas resource alone represents about 36 years of current consumption. One Tcf of natural gas is enough to heat 15 million homes for 1 year, generate 100 billion kilowatt-hours of electricity, or fuel 12 million natural-gas-fired vehicles for 1 year.

Developing domestic natural gas resources means additional jobs (economic growth) when wells are drilled, pipelines are constructed, and production facilities are built and operated. In addition, higher volumes of available domestic natural gas mean lower fuel or feedstock prices for industries that use natural gas to process or manufacture products. This means fewer jobs lost to lower-cost overseas competitors, as well as lower prices for consumers.



The EIA's Annual Energy Outlook for 2011 shows the contribution of shale gas to U.S. natural gas production reaching 45% by 2035.

Shale gas production also means increased tax and royalty receipts for state and federal government, and increased economic activity in producing areas from royalty and bonus payments to landowners. This influx of revenue can be used to enhance public services.

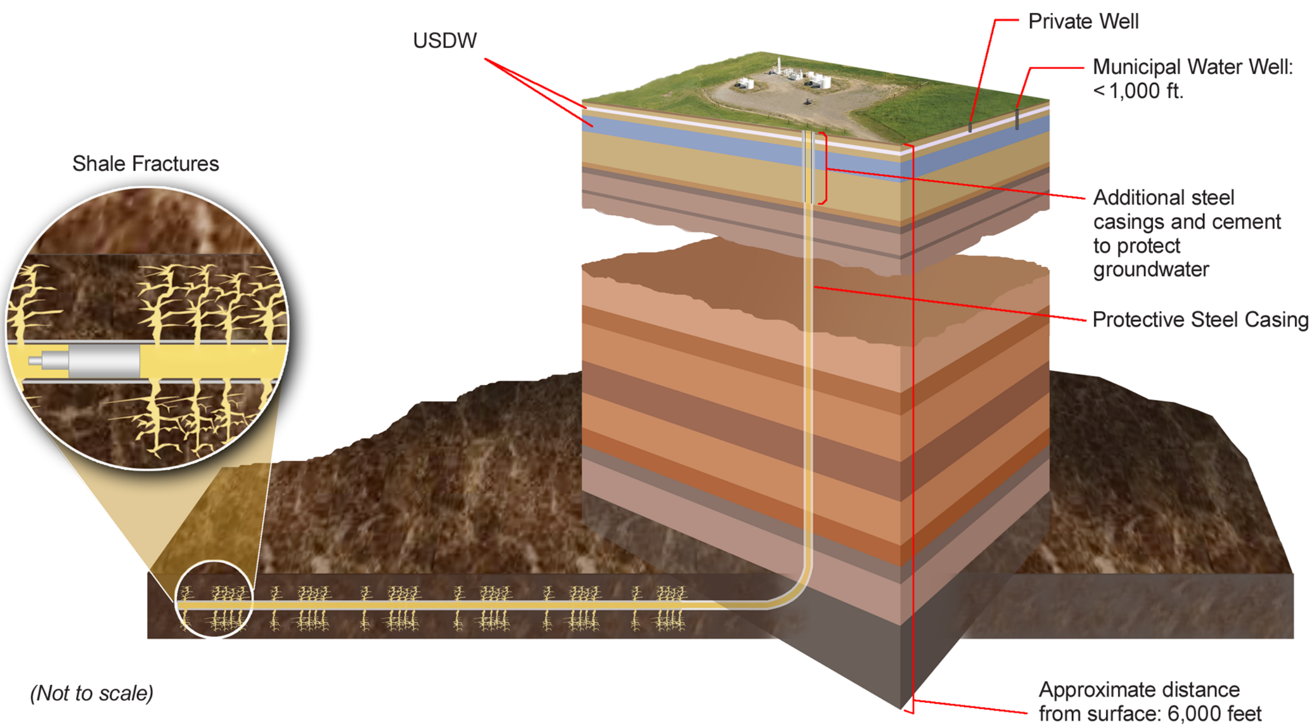
The Technology

How it works

Wells are drilled vertically to intersect the shale formations at depths that typically range from 6,000 to more than 14,000 feet. Above the target depth the well is deviated to achieve a horizontal wellbore within the shale formation, which can be hundreds of feet thick. Wells may be oriented in a direction that is designed to maximize the number of natural fractures present in the shale intersected. These natural fractures can provide pathways for the gas that is present in the rock matrix to flow into the wellbore. Horizontal wellbore sections of 5,000 feet or more may be drilled and lined with metal casing before the well is ready to be hydraulically fractured.

Hydraulic fracturing

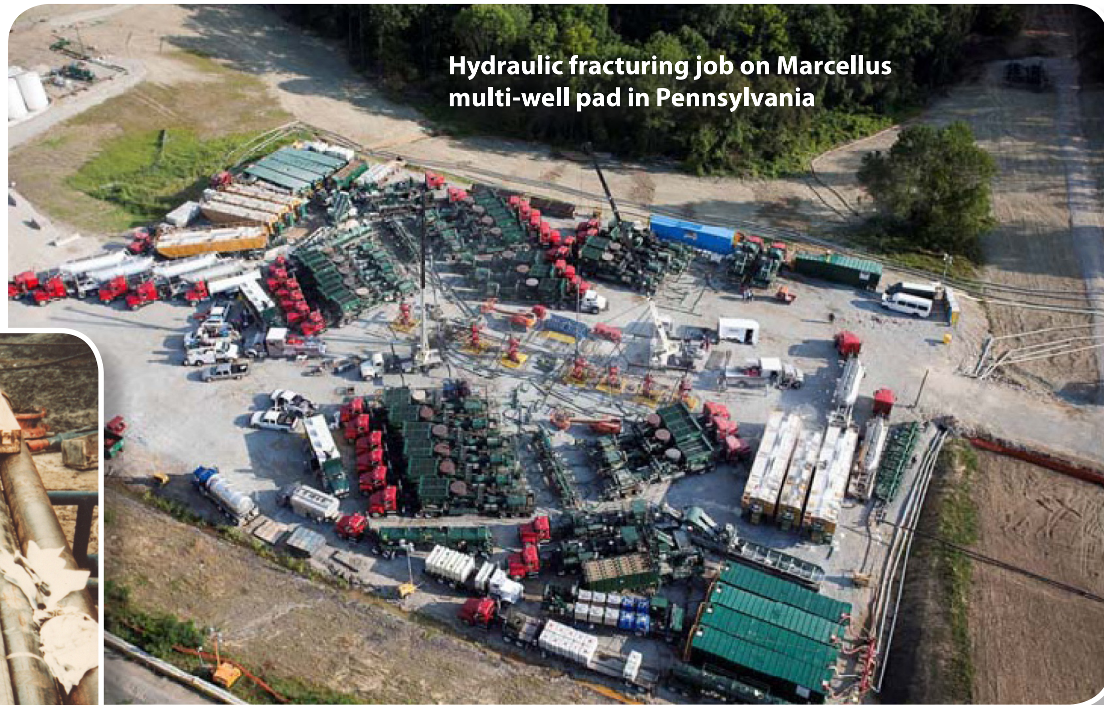
Beginning at the toe of the long horizontal section of the well, segments of the wellbore are isolated, the casing is perforated, and water is pumped under high pressure (thousands of pounds per square inch) through the perforations, cracking the shale and creating one or more fractures that extend out into the surrounding rock. These fractures continue to propagate, for hundreds of feet or more, until the pumping ceases. Sand carried along in the water props open the fracture after pumping stops and the pressure is relieved. The propped fracture is only a fraction of an inch wide, held open by these sand grains. Each of these fracturing stages can involve as much as 10,000 barrels (420,000 gallons) of water with a pound per gallon of sand. Shale wells have as many as 25 fracture stages, meaning that more than 10 million gallons of water may be pumped into a single well during the completion process. A portion of this water is flowed back immediately when the fracturing process is completed, and is reused. Additional volumes return over time as the well is produced.



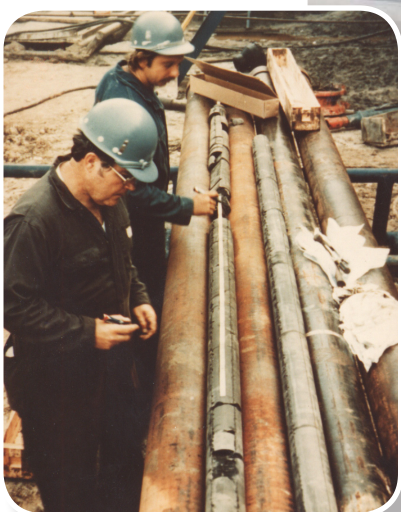
Steel casing lines the well and is cemented in place to prevent any communication up the wellbore as the fracturing job is pumped or the well is produced. Shallow formations holding fresh water that may be useful for farming or public consumption are separated from the fractured shale by thousands of feet of rock.

NETL's early contributions

In the 1970s, fears of dwindling domestic natural gas supplies spurred DOE researchers to examine alternative sources of natural gas in unconventional reservoirs such as shales, coal seams, and tight sandstones. NETL helped to advance foam fracturing technology, oriented coring and fractographic analysis, and large-volume hydraulic fracturing. In 1975, a DOE-industry joint venture drilled 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. DOE integrated basic core and geologic data from 35 research wells to prepare the first, publicly available estimates of technically recoverable gas for gas shales in West Virginia, Ohio, and Kentucky.



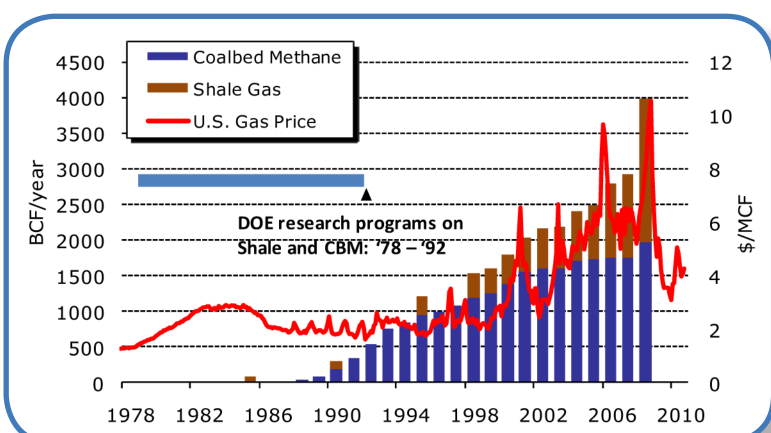
Hydraulic fracturing job on Marcellus multi-well pad in Pennsylvania



DOE researchers gathering data from one of a series of cored shale wells in the Appalachian Basin in the early 1980s.

DOE's important contributions to shale gas development have been recognized by many. According to Penn State University's Dr. Terry Engelder, a recognized expert on the Marcellus Shale, DOE's Eastern Gas Shales Research Program "helped expand the limits of gas shale production and increased understanding of production mechanisms. It is one of the great examples of value-added work led by the DOE." In his recent paper summarizing thirty years of gas shale fracturing, George E. King, Global Technology Consultant for Apache Corporation, states that "Technology developments in the North American Devonian shale during the late 1970s and proceeding into the 90s, chiefly from a loose alliance of the U.S. Department of Energy, the Gas Research Institute and numerous operators, combined to collectively produce several breakthroughs … horizontal wells, multi-stage fracturing and slick water fracturing." Fred Julander of Julander Energy, a 36-year independent producer and a member of the National Petroleum Council, has stated that "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."

For example, EQT, an independent producer in Pittsburgh, PA, has been developing the Huron Shale in Eastern KY using air drilling technology that relies on electromagnetic telemetry (EMT) to directionally drill horizontal wellbores. EQT reports that it is currently producing more than 100 million cubic feet per day (MMcfd) from its Huron wells and believes the resource potential could be as much as 10 Tcf of gas equivalent. The EMT technology now offered by Sperry Drilling (a Halliburton service line) has its roots in DOE research from the 1980s and 90s. "In the early 1980s, the industry as a whole did not have a clear vision for producing gas from shales and benefited from DOE involvement and funding of EMT technology… there is a clear line of sight between the initial research project and the commercial EMT service available today," states Dan Gleitman, Sr. Director – Intellectual Asset Management, Halliburton.



DOE research during the 1980s played a role in the growth of unconventional gas production that is now helping to reduce the price of natural gas to consumers

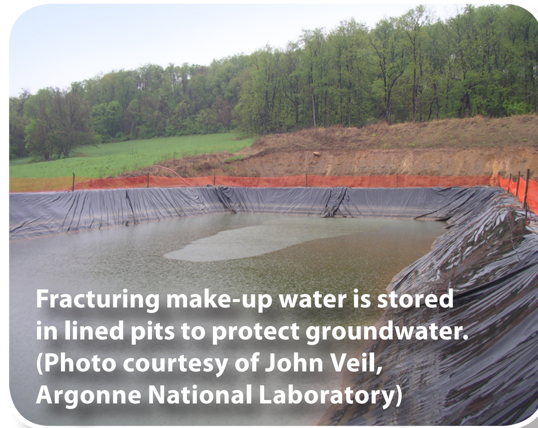
While decades of technological enhancements stand behind the suite of tools and methodologies that make shale gas production possible, publicly funded R&D has played an important role. NETL continues to manage a suite of research projects focused on increasing the supply of domestic natural gas to the consumer, in an environmentally sustainable and increasingly safe manner.

What's Next

What DOE is doing now

Currently, NETL is actively involved in advancing technologies that can help producers develop shale gas resources in the most environmentally responsible manner. Research is under way to find improved ways to treat fracture flowback water so that it can be reused or easily disposed of and to reduce the "footprint" of shale gas operations so that there is less disruption of the surface during drilling and completion operations.

DOE is refocusing the work done under Section 999 (Subtitle J) of the Energy Policy Act of 2005 on safety, environmental sustainability, and quantifying the risks of exploration and production activity.



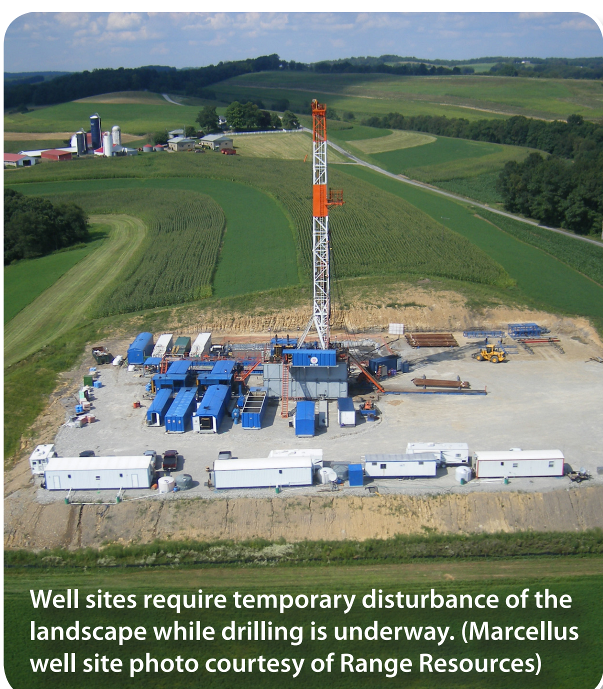
Fracturing make-up water is stored in lined pits to protect groundwater. (Photo courtesy of John Veil, Argonne National Laboratory)

DOE is working closely with the U.S. Environmental Protection Agency (EPA) as it carries out an exhaustive study to quantify the potential risk of hydraulic fracturing to underground sources of drinking water. NETL is also collaborating with the Department of Interior to enhance understanding of these risks.

Fracturing trucks on location at a Pennsylvania Marcellus location. (Photo courtesy of John Veil, Argonne National Laboratory)

Recent years have witnessed a number of initiatives to address the challenges of producing shale gas, sponsored by states, environmental groups, industry advocacy groups, and research organizations. DOE is exploring creation of a Shale Gas Initiative, in cooperation with public, private and non-governmental stakeholders, to build on these efforts and identify "best practices" that could be used by both operators and regulatory agencies to raise the bar on safety and environmental sustainability during shale gas development.

The U.S. Department of State has launched a U.S.-China Shale Gas Resource Initiative to help reduce greenhouse gas emissions, promote energy security and create commercial opportunities for U.S. companies. To date, the effort has engaged hundreds of Chinese technologists, facilitated a Chinese delegation's visit to a U.S. shale gas development operation, and created interest in American unconventional gas technologies through forums and workshops.



Well sites require temporary disturbance of the landscape while drilling is underway. (Marcellus well site photo courtesy of Range Resources)

DOE has worked with states through the Ground Water Protection Council (GWPC) to develop and maintain the Risk-Based Data Management System (RBDMS). Nationwide, 20 states and one Indian Nation now use the RBDMS to help operators comply with regulations. DOE has recently enhanced the RBDMS to track and record data related to hydraulic fracturing treatments. DOE has also funded in part, a Hydraulic Fracturing Chemical Registry to be hosted by the GWPC and Interstate Oil and Gas Compact Commission (IOGCC). This website will be a means for the industry to voluntarily supply hydraulic fracturing chemical data in a consistent and centralized location.

In 2009, DOE teamed with IOGCC to form a Shale Gas Directors Task Force to serve as a forum for states to share insights on issues and innovations related to shale gas development at the local, state and federal levels. More information is available at www.iogcc.org and http://groundwork.iogcc.org.

While it will be impossible to extract shale gas without some temporary disruption to the rural landscape, new and existing technologies can be employed to limit this disruption, to mitigate any surface impacts, and to minimize impacts to other natural resources in the process.

Where to find out more

You can find out more about shale gas from these resources:

- **NETL website –** The National Energy Technology Laboratory has a complete list of research projects, with details about objectives, accomplishments, expected benefits and results, at http://www.netl.doe.gov/.

- **DOE website –** The Department of Energy has information available on Department objectives and accomplishments related to natural gas at http://energy.gov/energysources/naturalgas.htm.

- **Marcellus Shale Coalition website –** This website has general information provided by an organization "committed to the responsible development of natural gas from the Marcellus Shale geological formation and the enhancement of the region's economy that can be realized by this clean-burning energy source" at http://marcelluscoalition.org/home/.

- **Groundwork –** The IOGCC website focuses on shale gas regulatory information at http://groundwork.iogcc.org.

- **Publications –** A number of publications have been produced by NETL and others that help to explain shale gas and the technologies involved. These include:
  - "Modern Shale Gas Development in the United States – A Primer," available for download at http://www.netl.doe.gov/technologies/oil-gas/publications/EPreports/Shale_Gas_Primer_2009.pdf
  - NETL's "E & P Focus Newsletter" provides updates on various shale gas research projects, available for download at http://www.netl.doe.gov/technologies/oil-gas/ReferenceShelf/epfocus.html
  - "An Emerging Giant: Prospects and Economic Impacts of Developing the Marcellus Shale Natural Gas Play," available for download at http://www.alleghenyconference.org/PDFs/PELMisc/PSUStudyMarcellusShale072409.pdf
  - "The Economic Impacts of the Pennsylvania Marcellus Shale Natural Gas Play: An Update," available for download at http://marcelluscoalition.org/wp-content/uploads/2010/05/PA-Marcellus-Updated-Economic-Impacts-5.24.10.3.pdf
  - "Developing the Marcellus Shale," available for download at http://www.pecpa.org/sites/pecpa.org/files/downloads/Developing_the_Marcellus_Shale_0.pdf
  - "Water Resources and Natural Gas Production from the Marcellus Shale," available for download at http://pubs.usgs.gov/fs/2009/3032/
  - "Homegrown Energy: The Facts About Natural Gas Exploration of the Marcellus Shale," available for download at http://www.marcellusfacts.com/pdf/homegrownenergy.pdf
  - "The Future of Natural Gas: An Interdisciplinary MIT Study," available for download at http://web.mit.edu/mitei/research/studies/naturalgas.html

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