Shale Gas: Development of the Most Active Plays in the United States

An Online Continuing Education Course for Engineers

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Shale formations across the U.S. have been developed to produce natural gas in small but continuous volumes since the earliest years of gas development. The first producing gas well in the U.S. was completed in 1821 in Devonian-aged shale near the town of Fredonia, New York. The natural gas from this first well was used by town residents for lighting. Early supplies of natural gas were derived from shallow gas wells that were not complicated to drill and from natural gas seeps. The shallow wells and seeps were capable of producing small amounts of natural gas that were used for illuminating city streets and households. These early gas wells played a key part in bringing illumination to the cities and towns of the eastern U.S.

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Other shale gas wells followed the Fredonia well with the first field-scale development of shale gas from the Ohio Shale in the Big Sandy Field of Kentucky during the 1920s. The Big Sandy Field has recently experienced a renewed growth and currently is a 3,000-square-mile play encompassing five counties. By the 1930s, gas from the Antrim Shale in Michigan had experienced moderate development; however, it was not until the 1980s that development began to expand rapidly to the point that it has now reached nearly 9,000 wells. It was also during the 1980s that one of the nation's most active natural gas plays initially kicked off in the area around Fort Worth, Texas. The play was the Barnett Shale, and its success grabbed the industry's attention. Large-scale hydraulic fracturing, a process first developed in Texas in the 1950s, was first used in the Barnett in 1986; likewise, the first Barnett horizontal well was drilled in 1992. Through continued improvements in the techniques and technology of hydraulic fracturing, the development of the Barnett Shale has accelerated. In the ensuing two decades, the science of shale gas extraction has matured into a sophisticated process that utilizes horizontal drilling and sequenced, multi-stage hydraulic fracturing technologies. As the Barnett Shale play has matured, natural gas producers have been looking to extrapolate the lessons learned in the Barnett to the other shale gas formations present across the U.S. and Canada.

In addition to the Barnett Play, a second shale play with greater oil production has also been advancing techniques related to horizontal wells and hydraulic fracturing. The Bakken Shale of the Williston Basin of Montana and North Dakota has seen a similar growth rate to the Barnett. The Bakken is another technical play in which the development of this unconventional resource has benefitted from the technological advances in horizontal wells and hydraulic fracturing. In April 2008, the United States Geological Survey (USGS) released an updated assessment of the undiscovered technically recoverable reserves for this shale play estimating there are 3.65 billion barrels (bbls) of oil, 1.85 tcf of associated natural gas, and 148 million bbls of natural gas liquids in the play.

The combination of sequenced hydraulic fracture treatments and horizontal well completions has been crucial in facilitating the expansion of shale gas development. Prior to the successful application of these two technologies in the Barnett Shale, shale gas resources in many basins had been overlooked. The reason for this was that production was not viewed as economically feasible. The low natural permeability of shale has been the limiting factor to the production of shale gas resources because it only allows minor volumes of gas to flow naturally to a wellbore. The characteristic of low-matrix permeability represents a key difference between shale and other gas reservoirs. For gas shales to be economically produced, these restrictions must be overcome. The combination of reduced economics and low permeability of gas shale formations historically caused operators to bypass these formations and focus on other resources.

Shale Gas – Geology

Shale gas is natural gas produced from shale formations that typically function as both the reservoir and source for the natural gas. In terms of its chemical makeup, shale gas is typically a dry gas primarily composed of methane (90% or more methane), but some formations do produce wet gas. The Antrim and New Albany formations have typically produced water and gas. Gas shales are organic-rich shale formations that were previously regarded only as source rocks and seals for gas accumulating in the stratigraphically-associated sandstone and carbonate reservoirs of traditional onshore gas development. Shale is a sedimentary rock that is predominantly comprised of consolidated clay-sized particles. Shales are deposited as mud in low-energy depositional environments such as tidal flats and deep water basins where the fine-grained clay particles fall out of suspension in these quiet waters. During the deposition of these very fine-grained sediments, there can also be deposition of organic matter in the form of algae-, plant-, and animal-derived organic debris.

EXHIBIT 1: MARCELLUS SHALE OUTCROP
Source: ALL Consulting, 2008

The naturally tabular clay grains tend to lie flat as the sediments accumulate and subsequently become compacted as a result of additional sediment deposition. This results in mud with thin laminar bedding that lithifies (solidifies) into thinly layered shale rock. The very fine sheet-like clay mineral grains and laminated layers of sediment result in a rock that has limited horizontal permeability and extremely limited vertical permeability. Typical unfractured shales have matrix permeabilities on the order of 0.01 to 0.00001 millidarcies. This low permeability means that gas trapped in shale cannot move easily within the rock except over geologic expanses of time (millions of years).

The natural layering and fracturing of shales can be seen in outcrop. Exhibit 1 shows a typical shale outcrop which reveals the natural bedding planes, or layers, of the shale and near-vertical natural fractures that can cut across the naturally horizontal bedding planes. Although the vertical fractures shown in this picture are naturally occurring, artificial fractures induced by hydraulic fracture stimulation in the deep subsurface reservoir rock would have a similar appearance.

The low permeability of shale causes it to be classified as an unconventional reservoir for gas (or in some cases, oil) production. Low permeability, often organic-rich units are also thought to be the source beds for much of the hydrocarbons produced in these basins. Gas reservoirs are classified as conventional or unconventional for the following reasons:

1. Conventional reservoirs – Wells in conventional gas reservoirs produce from sands and carbonates (limestones and dolomites) that contain the gas in interconnected pore spaces that allow flow to the wellbore. Much like a kitchen sponge, the gas in the pores can move from one pore to another through smaller pore-throats that create permeable flow through the reservoir. In conventional natural gas reservoirs, the gas is often sourced from organic-rich shales proximal to the more porous and permeable sandstone or carbonate.

2. Unconventional reservoirs – Wells in unconventional reservoirs produce from low permeability (tight) formations such as tight sands and carbonates, coal, and shale. In unconventional gas reservoirs, the gas is often sourced from the reservoir rock itself (tight gas sandstone and carbonates are an exception). Because of the low permeability of these formations, it is typically necessary to stimulate the reservoir to create additional permeability. Hydraulic fracturing of a reservoir is the preferred stimulation method for gas shales. Differences between the three basic types of unconventional reservoirs include:

    - Tight Gas – Wells produce from regional low-porosity sandstones and carbonate reservoirs. The natural gas is sourced (formed) outside the reservoir and migrates into the reservoir over time (millions of years). Many of these wells are drilled horizontally, and most are hydraulically fractured to enhance production.

    - Coal Bed Natural Gas (CBNG) – Wells produce from the coal seams which act as source and reservoir of the natural gas. Wells frequently produce water as well as natural gas. Natural gas can be sourced by thermogenic alterations of coal or by biogenic action of indigenous microbes on the coal. There are some horizontally drilled CBNG wells and some that receive hydraulic fracturing treatments. However, some CBNG reservoirs are also underground sources of drinking water, and as such there are restrictions on hydraulic fracturing. CBNG wells are mostly shallow, as the coal matrix does not have the strength to maintain porosity under the pressure of significant overburden thickness.

- Shale Gas – Wells produce from low permeability shale formations that are also the source for the natural gas. The natural gas volumes can be stored in a local macro-porosity system (fracture porosity) within the shale, or within the micro-pores of the shale, or it can be adsorbed onto minerals or organic matter within the shale. Wells may be drilled either vertically or horizontally and most are hydraulically fractured to stimulate production. Shale gas wells can be similar to other conventional and unconventional wells in terms of depth, production rate, and drilling.

Sources of Natural Gas

Shale gas is both created and stored within the shale bed. Natural gas (methane) is generated from the organic matter that is deposited with and present in the shale matrix.

In order for shale to have economic quantities of gas it must be a capable source rock. The potential of a shale formation to contain the economic quantities of gas can be evaluated by identifying specific source rock characteristics such as total organic carbon (TOC), thermal maturity, and kerogen analysis. Together, these factors can be used to predict the likelihood of the prospective shale to produce economically viable volumes of natural gas. A number of wells may need to be analyzed in order to sufficiently characterize the potential of a shale formation, particularly if the geologic basin is large and there are variations in the target shale zone.

Shale Gas in the United States

Shale gas is present across much of the lower 48 States.. The most active shales to date are the Barnett Shale, the Haynesville/Bossier Shale, the Antrim Shale, the Fayetteville Shale, the Marcellus Shale, and the New Albany Shale. The following discussion provides a summary of basic information regarding these shale gas plays.

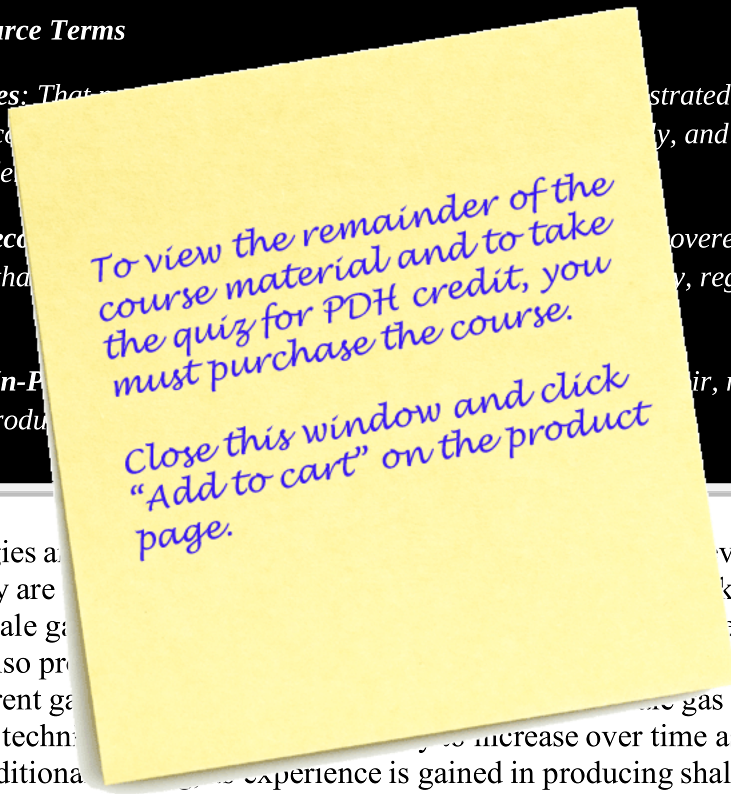
Each of these gas shale basins is different, and each has a unique set of exploration criteria and operational challenges. Because of these differences, the development of shale gas resources in each of these areas faces potentially unique challenges. For example, the Antrim and New Albany Shales are shallower shales that produce significant volumes of formation water unlike most of the other gas shales. Development of the Fayetteville Shale is occurring in rural areas of north central Arkansas, while development of the Barnett Shale is focused in the area of Forth Worth, Texas, in an urban and suburban environment.

Key Gas Resource Terms

Proved Reserves: *That ... strated by actual production or c... y, and legally producible unde...*

Technically Reco... *... overed and undiscovered, tha... y, regardless of economics.*

Original Gas-In-P... *... ir, regardless of the ability to produ...*



As new technologies a... ved to have limited economic viability are ... key characteristics of the most active shale ga... elated to the character of the shale and also pr... ristics that are used to evaluate the different ga... gas resource, especially the portion that is techn... increase over time as new data become available from additiona... experience is gained in producing shale gas, as understanding of the resource characteristics increases, and as recovery technologies improve.