Article

Shale Gas: the technology behind the revolution

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October 2012.
Shale gas reservoir development is a growing source of domestic natural gas production across the United States. The combination of two innovative technologies – horizontal drilling and hydraulic fracturing – have enabled economic production of the country’s indigenous unconventional gas reserves, drastically changing the national energy market. Hydraulic fracturing, commonly referred to as ‘fracking’, is a proven technology which has been used for about 60 years on more than million wells allowing producers to recover natural gas and oil from deep shale formations. However, during the last decade, the application of this technology has been accompanied by debates on the associated risks and environmental impacts.

This article aims to provide an overview of the main techniques used for shale gas production, its associated risks and environmental impacts, and presents a number of potential challenges for the new entrants into the shale gas business.

Conventional vs. unconventional

The idea of producing natural gas from shale formations is not new; shale gas has been produced in the US in small quantities since the 1940s. However, due to the low productivity of shale wells and relatively high costs, the production of this gas was considered a small-scale niche and therefore did not attract much attention from oil and gas majors. Techniques for natural gas production from shale have improved dramatically over time, most significantly in the last two decades. A significant breakthrough was achieved in 1991 when George Mitchell, an American geologist, combined the techniques of horizontal drilling and hydraulic fracturing, allowing greater yields of shale gas and setting the stage for the American shale gas revolution.

To understand the need for these techniques, the differences between conventional and unconventional gas production have first to be explained (figure 1). In general, natural gas is formed by thermal transformation of an organic-rich source rock. In conventional natural gas reservoirs gas is trapped in a porous rock (e.g. sandstone), sealed with an impermeable cap rock (typically a salt layer), which prevents the gas from migration to upper layers. From such a conventional reservoir natural gas can be recovered by vertical (i.e. conventional) drilling. A conventional natural gas well typically reaches between 1500 and 3000 meters beneath the surface, and is exclusively vertical. Conventional natural gas reservoirs usually have high productivity due to two essential properties - high porosity and permeability. These two reservoir properties ensure that the gas can easily migrate through the reservoir pores to the wellbore. Conversely, gas shales (organic-rich shale formations) are characterized by a source rock with low porosity and low permeability. Because of these poor properties, gas cannot flow to the wellbore easily, and therefore requires an additional stimulation, such as hydraulic fracturing.

The process of shale gas production begins with drilling a vertical well. Since shale gas deposits are located deeper than the conventional gas reservoirs, this vertical section can reach depths of 1500 to 3800 meters. At such depths, the well continues to be drilled in the horizontal direction by using directional drilling equipment or a so-called ‘horizontal drilling technique’. This technique provides increased wellbore exposure to the deep reservoir area, allowing for a reduced number of surface drilling installations. It is worth mentioning that the angle of inclination used to drill the horizontal section of the well, which can reach up to 5 km in length, does not necessarily have to reach 90° for the well to be considered a horizontal well.

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* Porosity is a measure of the void spaces in a material.
† Permeability is a measure of the ability of a porous material to allow fluids to pass through it.
In addition to horizontal drilling, hydraulic fracturing or fracking is another key technology, which enabled economic production of shale gas in the United States. This technique is used to create additional permeability in a producing formation, allowing the gas to flow more easily towards the wellbore. When the horizontal well is completed and the well casings are set (required to isolate the overlying zones and to guarantee well integrity), parts of the casing in the horizontal section of the well are perforated (figure 2). The perforation is done by the use of a perforating gun, which ‘punches’ small holes in the well casing, cement and eventually the rock. Afterwards, a large amount of fracturing fluid, consisting of water, sand and additives (defined later), is pumped into the well and pushed though the created perforations under high pressure. In this way, microscopic cracks in the rock formation are created, allowing the natural gas to flow from the rock into the wellbore.

Shale gas wells are usually fractured in stages, and each stage is designed to fracture the rock a certain distance (about 60 m) from the well. A special plug is set between each stage in order to maintain pressure and achieve maximum fracturing results. The sand is used in the fracturing fluid as a 'propping' agent to fill the created cracks so that they remain open when the pressure is relieved, allowing shale gas production to take place. Additives are used in the fracture fluid to assist the process, i.e. help to reduce friction, prevent bacterial growth and protect the equipment. After all fracturing stages are complete, the plugs are drilled out, the production wellhead is put in place and production begins.

**The evolution of techniques**

Hydraulic fracturing is often referred to as a technology that has been used for decades in the gas industry. However, there are some major differences between the way this technology is used now and in the past.

Hydraulic fracturing, as it is currently used for the shale gas production, was developed in the late 1990s. This technique is called ‘slick-water hydraulic fracturing’, since it uses a different mix of...
additives than previous methods, reducing the amount of gelling agents and adding friction reducers, which allow the fluid to flow more easily. The modern technology is also known as ‘high-volume hydraulic fracturing’ (HVHF), since it uses larger amounts of fluid, on average 20,000 - 30,000 m³ to fracture a well, compared to 75 to 300 m³ used in the ‘original’ hydraulic fracturing. The exact amount of fluid used depends on the depth and horizontal length of the wellbore, as well as the number of fractures created along it.

Over time, the use of both horizontal drilling and hydraulic fracturing techniques was perfected by small oil and gas service companies. Shale gas currently represents about 20% (138 billion cubic meters) of total US gas production and is projected to reach 50% by 2035. Already with the current production level the US has taken the world’s top producer position and transformed from the world’s largest gas consumer to a potential gas exporter.

Developments in the shale gas industry can be seen in the example of the Southwestern Energy Company’s practices in the Fayetteville shale from 2007 to 2009 (Figure 3). Figure 1 demonstrates that in just over two years, the time required for drilling one horizontal well decreased by 45%, while the average length of a horizontal well section almost doubled, resulting in a significant increase in the average shale gas production rate. At the same time, production costs (drilling and well completion costs) remained nearly unchanged, while gas transportation costs were very low, since the location of shale gas production sites in the US tend to be in the vicinity of large high pressure (HP) trunk lines. This combination of improvements allowed each rig to produce more wells on an annual basis, resulting overall in a more than five-fold increase in annual shale gas production.

World distribution of shale gas and current activities

In the context of the advances described the question should be asked: Are world’s shale gas reserves large enough to sustain the current production boom? The US Energy Information Administration (EIA) in its recent report examined 48 shale gas basins in 32 countries and estimated a technically recoverable‡ shale gas resource base in the assessed regions of 6,622 trillion cubic feet (tcf) or 187.5 trillion cubic meters (tcm). However, it seems likely that the global shale gas potential is even higher, taking into account that such regions as Russia, central Asia, the Middle East, south-east Asia and central Africa were excluded from the EIA analysis. To put these estimates in perspective, world proven natural gas reserves were about 6,700 tcf (189.3 tcm) at the end of 2010, implying that solely shale gas resources can double this amount.

According to these estimates, the US holds about 862 tcf (24.5 tcm) of technically recoverable shale gas resources, which is about 3 times the amount of proven commercial reserves of natural gas and 40 years supply at present consumption rates. Besides the US, the largest identified resources are located in China (1,275 tcf), Argentina (774 tcf), Mexico (681 tcf), South Africa (485 tcf), Australia (396 tcf), Canada (388 tcf), Libya (290 tcf), Algeria (231 tcf), Brazil (226 tcf), Poland (187 tcf) and

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‡Technically recoverable resources are defined as “resources in accumulations producible using current recovery technology but without reference to economic profitability”
France (180 tcf). The amount of these shale gas resources that will be developed in the future mainly depends on demand, the reachable volume (taking into account social and environmental challenges) and developments in technology allowing shale gas to be extracted at lower cost."

Currently, dozens of companies are involved worldwide in shale gas activities. Outside of the US, around 50 companies are currently active in shale gas exploration in Europe, including majors, such as Exxon Mobil, Shell, Total, Conoco Philips, and Chevron, as well as small state oil & gas companies. The majority are involved in data acquisition for appraisal purposes. A number of international oil companies, led by Exxon, have already obtained exploration licences in Poland, Hungary, Germany, Romania, Sweden and the UK. However, most of the majors focus on Poland, which has significant shale deposits with a geology similar to the Barnett Shale in Texas (the first ‘play’, or area, where economic production of shale gas began), and which has already granted licences covering about 40% of its land in the hope of replicating the US experience. The level of success of shale gas in Poland is difficult to predict in the current environment. In January 2012, Exxon decided to end their search for Polish shale gas after drillings at two sites failed to yield a commercial gas flow.

Outside of Europe, the domestic production of shale gas could help to resolve many countries’ growing dependence on energy imports. In this respect China, the world’s biggest energy user, also hopes that shale gas could become an abundant and cheap new fuel source. Recently, Beijing has made shale gas a key part of its five-year energy blueprint, aiming to reach production from the current non-commercial output to 60 bcm in 2020. In March 2012, Chinese state-owned China National Petroleum Corporation (CNPC) signed its first production sharing contract with Royal Dutch Shell for shale gas in China. In a release on the Shell website, the company stated that it will apply its advanced technology, operational expertise and global experience in the project to jointly develop shale gas resources with CNPC. Other foreign oil and gas companies that have been negotiating joint shale gas exploration and production activities in China include BP, Chevron, Statoil ASA and French Total.

### Risks and environmental impacts associated with hydraulic fracturing

As with immense gas production, the application of fracking raises many questions regarding its impact on human health and the environment. A recent report of the Tyndall Centre (2011) assessed the possible risks and impacts of hydraulic fracturing and shale gas drilling. Several key risks related to the use of water and the chemical composition of the fracturing fluids were identified in their report.

In currently applied techniques, the volume of water used for fracturing process (i.e. fracking fluid) is large (about 20,000 m³) and on average 15% to 80% of the initially injected volume, so called flowback, is returned to the surface after the fracturing procedure. Fracturing fluid typically consists of 98% to 99.5% water and sand, as well as a wide spectrum of additives (0.5 – 2%), depending on the conditions of the specific well. Until recently, these substances were generally considered proprietary knowledge of the drilling companies and were not disclosed. Currently, due to concerns raised about potential groundwater contamination, this situation is changing and a few states in the US already require or are moving to require such disclosure. The substances added to fracking fluids may include potassium chloride, guar gum (commonly used in ice cream), ethylene glycol, sodium carbonate, potassium carbonate, sodium chloride, borate salts, citric acid (Vitamin C), glutaraldehyde, petroleum distillate, and isopropanol. Even though these components are also used in such industrial sectors as cosmetics, food and in the household/detergent industry, several critics argue that their application in hydraulic fracturing puts groundwater, and therefore human health, at risk. Issues of groundwater contamination with fracking fluid remain heavily disputed. The U.S. Environmental Protection Agency (EPA) is currently performing a large study, but its results will only be announced in 2014.

Another risk associated with fracking is disposal of wastewater. Reaching the surface, flowback water still contains additives, but also some heavy metals and radioactive elements absorbed from the fractured layers in the shale formation. Due to its potential toxic natures, this water must be handled and disposed of appropriately.

Seismicity is another potential risk associated with hydraulic fracturing. According to Daly (2011), several cases of earthquakes have reportedly been caused by hydraulic fracturing. For instance, two earthquakes (2.3 and 1.5 on a ‘10 scale’ Richter magnitude scale; the earthquake of 11 March 2011 in Japan was a magnitude 9.0) were recently registered in Lancashire, the UK. These

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8 Tyndal Centre for Climate Change Research is a research organization based in the UK, founded in 2000 by seven universities, including such universities as University of Cambridge, University of Manchester and University of Oxford. This organization is primarily founded by the host universities and by research grant.
tremors were a result of the fracking activities of Cuadrilla Resources, according to a recent report from The Department of Energy and Climate Change of the UK. Being the first company to explore for shale gas in the UK, Cuadrilla was required to suspend its hydraulic fracturing operations in the Lancashire area.14 Outside the UK, a strong rise in seismic events was registered in the US state of Oklahoma, an area where a large amount of fracturing activity has been performed.17

Due to these risks and environmental considerations, several countries in the world, particularly European countries as France and Bulgaria, imposed a moratorium on hydraulic fracturing until sufficient research on the economic, social and environmental impact of shale gas development is performed. This decision was based on strong opposition and protests from environmental organisations and residents living in the vicinity of proposed shale gas development activities.

Main challenges for new entrants

The risks associated with hydraulic fracturing are not the only challenges related to shale gas production. For other countries to be able to unlock their shale gas resource potential, several issues need to be taken into consideration. Depending on the country, geology can represent one of the major challenges to shale gas production. Shale deposits in the U.S. are shallow and the basins themselves are large, which made the application of horizontal drilling and fracturing techniques a success.17 In other parts of the world, particularly in Europe, the geology is different so is the population density, another potential challenge. For economically viable shale gas production, several drilling rigs and wells are required to be placed relatively close to each other, and new road and pipeline infrastructure needs to be developed. Countries with a high shale gas potential, such as China or Poland, are in general more densely populated than the US, leaving less opportunities for shale gas development. In order to reduce land use requirements, several technological approaches have been developed in the US, including a so-called ‘superpad’ approach. Instead of drilling evenly spaced vertical wells, ‘superpads’ engage a group of wellheads, which are clustered together, while the well shafts “splay out” into the gas field below the surface. This is a more expensive technique, however these additional costs may be offset by the reduced social costs associated with lower land use in densely populated areas.18

In addition, countries outside the US lack experience with shale gas production and face significant equipment shortages. The US is a ‘home’ for many rig facilities companies and retains an experienced drilling workforce.

Nevertheless, acceptance by local communities is likely to present the major challenge for the development of shale gas in other parts of the world, and particularly in Europe.17 This relates not only to the environmental impacts and risks associated with the use of fracturing techniques, but also to the question ‘what’s in it for me?’ In case of the US the mineral rights are owned by local residents, which they can sell, making a substantial profit. For instance, in New York State some residents were offered $5500 an acre, with 20% royalties on whatever gas is extracted.17 On the contrary, in many EU countries and other parts of the world, these rights are owned by the state, which leaves local residents with only minor benefits. Increased vehicle movement, and the landscape and noise pollution associated with shale exploitation may also be of significant concern locally, especially when considering the scale of development required to deliver significant supplies and lack of compensation for these impacts.

Concluding remarks

The use of horizontal drilling in combination with hydraulic fracturing has expanded the ability of oil and gas companies to economically produce natural gas from low permeability shale formations in the US. Nevertheless, the application of these techniques is often accompanied by many questions related to the risks involved and the associated environmental impacts. Even though both techniques are constantly improving, minimizing risks and maximizing the efficiency, there is still a need for an extensive monitoring and research in order to entirely evaluate the environmental impacts of shale gas production.

Besides the US, there is a high shale gas resource potential in other parts of the world, and several activities with respect to exploration and production of these resources have already been initiated by oil and gas majors. However, due to the challenges discussed in this paper, the rapid replication of the American success in those regions is still questionable.
Innovation and Peaks in the Delta.
financed by the European Union, European Fund for Regional Development, The Ministry of Economic Affairs, Agriculture and
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EDIaal project is partly made possible by a subsidy granted by The Northern Netherlands Provinces (SNN). EDIaal is co-
EDIAAL is an Energy Delta Institute programme that aims to gather, edit and make available independent knowledge on the
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This article was written within the framework of the EDIaal program

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