5

The Expansion of Unconventional Production of Natural Gas (Tight Gas, Gas Shale and Coal Bed Methane)

Alejandro Alonso Suárez
National Energy Commission, Spain

1. Introduction

Finding new oil reserves is becoming more and more difficult (al-Husseini, 2007). A recent study (Aleklett, 2007) alerted that global oil production has very probably passed its maximum, so the World will have reached the Peak of the Oil Age (also known as Hubbert Peak). The rate of discoveries of new oil reserves is less than the present rate of consumption, and already 5 out of every 6 oil producing countries have declining production. World natural gas proved reserves in 2010 were sufficient to meet 59 years of global production while proved oil reserves were sufficient to meet 46 years of global production (BP, 2011).

Natural gas production was expected to begin declining at the United States at the beginning of the XXI century, and in fact, conventional gas production peaked 15 years ago.

However, in the last decade, US internal gas production has been maintained and even increased in 2008. More surprisingly, US domestic gas resources have increase a 40% since 2006. Most of the growth in natural gas production in the United States and in other developed countries like Australia is coming from unconventional sources of natural gas that were considered until recently as non recoverable resources.

New and advanced exploration, well drilling and completion technologies are allowing increasingly better access to non conventional gas resources at competitive prices, so unconventional gas is becoming more "conventional". As most of discoveries are taking place in the US, they have a tremendous impact on global gas markets.

As a prove of the interest of the industry on unconventional gas, in December 2009, ExxonMobil announced it would buy XTO Energy, the bigger independent gas producer in US, one of the companies operating in the big Barnett Shale basin (Texas), for 31,000 million dollars.

Unconventional gas is defined by the International Energy Agency as gas that is more technologically difficult or more expensive to produce that conventional gas. Unconventional gas resources can be divided into coal bed methane, tight gas and shale gas. Other huge unconventional resources are gas hydrates (methane molecules trapped in crystalline water compounds), but they are not expected to provide a major contribution to gas production in the next 20 years.

A generally accepted industry definition is reservoirs that do not produce economic volumes of natural gas without assistance from massive stimulation treatments or special recovery processes and technologies, such as multiple fracturing.

This paper presents a review of the state of art and recent developments of unconventional gas production (tight gas, shale gas and coal bed methane): technology, pioneers projects and bigger unconventional fields, actual production, costs trends and potential reserves.

2. Types of non conventional natural gas

Fossil fuels - including crude oil and natural gas – were originated from organic matter over hundreds of millions of years. The organic matter, buried under layers of mud in anaerobic conditions (without oxygen), gradually decomposed and was converted into petroleum (natural gas or crude oil) by the combined action of heat and high pressure,

Gas generated in the process migrates towards the surface (the atmosphere) unless it encounters various types of geological traps in the form of porous rock formations tightly sealed by overlying layers of impermeable rock.

Natural gas yields can be broadly classified into conventional and non conventional reservoirs:

- In a **conventional reservoir**, natural gas is trapped in a limited boundary within porous rocks by impermeable rocks above (seal) that prevents it from escaping to the surface. Usually have as well a down-dip water contact. This led to the formation of conventional gas deposits, resembling gas-soaked sponges. The natural gas can be "associated" (mixed with oil) or "non-associated" found in reservoirs that do not contain oil. The majority of gas production is non-associated.
  Non-associated gas is recovered from the formation by an expansion process. Wells drilled into the gas reservoir allow the highly compressed gas to expand through the wells in a controlled manner, to be captured, treated and transported at the surface. This expansion process generally leads to high recovery factors from conventional, good-quality gas reservoirs. If, for example, the average pressure in a gas reservoir is reduced from an initial 300 bar to 60 bar over the lifetime of the field, then approximately 80% of the gas initially in place will be recovered.
- **Unconventional reservoirs** are more continuous, consisting of a stacking of sedimentary layers with low permeability that are charged with gas.
  They usually require advanced technology such as horizontal wells or artificial stimulation in order to be economically productive; recovery factors are much lower — typically of the order of 15 - 20% of the gas in place.

The unconventional gas sources include shale gas, gas locked in insulated rock pores (tight gas), coal bed methane and gas hydrates. Important characteristics of gas reservoirs are porosity - the volume of the pore spaces, and permeability - how connected the pore spaces are.

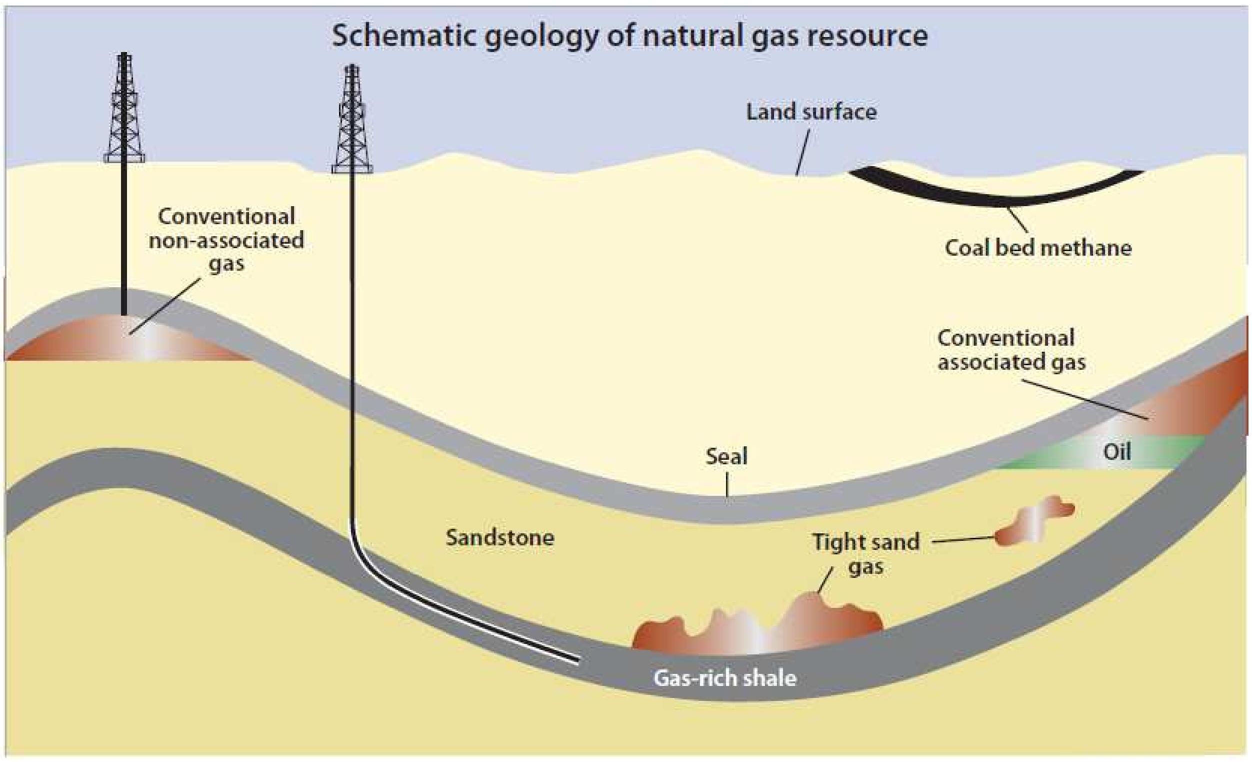


Fig. 1. Types of gas yields. Source US Energy Information Administration, 2011.

2.1 Tight gas

Tight Gas is natural gas found in reservoirs with low porosity and low permeability. Tight reservoirs are usually a sandstone formation that is unusually non-porous, although carbonate rocks can also be tight-gas producers.

Tight gas is trapped in geological formations similar to conventional gas, so the distinction between conventional and tight gas is not so clear in some basins.

The standard definition for a tight-gas reservoir is a rock with matrix porosity of 10% or less and permeability of 0.1 millidarcy or less.

Low permeability is primarily due to the fine-grained nature of the sediments, compaction, or infilling of pore spaces by carbonate or silicate cements.

Gas production from a tight-gas well will be low compared with gas production from conventional reservoirs (MIT, 2010). A lot of wells have to be drilled to get most of the oil or gas out of the ground in unconventional reservoirs. Tight gas requires multiple fracturing in order for any significant amount of gas to be available.

Exploration for tight gas sand reservoirs differs from conventional reservoirs in that tight gas sands are continuous, consisting of a stacking of sedimentary layers that are charged with oil or gas much in the same way that an aquifer is charged with water. Conventional reservoirs have much more limited boundaries, and well as a down-dip water contact, which is absent from the continuous reservoirs. Also, the great preponderance of continuous reservoirs are charged with gas, rather than crude oil.

While some continuous reservoirs may be found at a relative shallow depth, many are located at greater depths of 3000 m.

The key to producing this vast resource is locating areas and drilling wells where natural fractures abound "a sweet-spot". The distribution, orientation, and density of these fractures is key to proper planning and well scheduling in tight gas reservoirs. Identifying the best locations for tight-gas well completions requires a host of reservoir evaluation technologies, including seismic interpretation, logging and well testing.

Unless natural fractures are present, almost all tight reservoirs must be fracture-stimulated to obtain economic production rates.

2.1.1 Tight gas sands resources

Although tight gas reservoirs are scattered across the planet, most are concentrated in North America, Russia and China.

Estimates put the total volume of these unconventional resources at 310,000 bcm. Until the past decade, tight gas was considered non-economic to produce, but improvements in technology have clearly made a big difference in the amount of unconventional gas that can be recovered economically.

Only a 10% recovery rates for this type of reservoir guarantees reserves of 30,000 bcm, a not-significant amount compared with the 187,000 bcm of proved conventional gas reserves for the total World (Kuuskraa & Stevens, 2009). However, unlocking them raises a number of challenges, both technical and financial.

Historically, tight gas has been the most significant source of unconventional gas production in the United States, and is likely to remain so for some time. Tracking tight gas production in the World can be difficult because it can exist in a continuum with conventional gas.

2.2 Shale gas

Shale Gas is natural gas that is produced from reservoirs predominantly composed of shale (a fine-grained sedimentary rock which is easily breakable into thin, parallel layers), rather than from more conventional sandstone or limestone reservoirs.

Shale has low matrix permeability, so gas production in commercial quantities requires fractures to provide permeability. While a gas well in a Qatari reservoir might produce 4 million m^3/day, a shale gas well (without stimulation) might produce only 0.15 million m^3/day.

Shale gas has been produced for years from shale with natural fractures; the shale gas boom in recent years has been due to modern technology in hydraulic fracturing to create extensive artificial fractures around well bores. Horizontal drilling is often used with shale gas wells, with lateral lengths up to 3000 meters within the shale, to create maximum borehole surface area in contact with the shale.

Unlike conventional gas production, shale gas potential is not confined to limited traps or structures, and may exist across large geographic areas. Total natural gas resource potential for gas shale at US has been estimated to be from 10 to 25 Tm^3 of recoverable gas resources (EIA, 2011), compared with the actual volume of 7.7 Tm^3 of proved gas reserves at US (BP, 2011).

At present, most commercial shale-gas development is in the US and Canada. To date, tight gas, as well as other unconventional resources, remains underexploited outside North America.

2.3 Coal bed methane

Coal Bed Methane (CBM) refers to gas that contains a high percentage of methane and comes from coal deposits underground. CBM is natural gas generated and stored in coal seams. Coal seams have a dual porosity system comprising micropores, which exist in the coal matrix, and a system of natural fractures called cleats, which are the macropores. In a CBM gas reservoir, water completely permeates coal beds, and its pressure causes the methane to be adsorbed onto the grain surfaces of the coal.

The ability for coal reservoirs to store coal-bed methane depends on pressure of the reservoir, composition of coal, coal rank, and structure of the micropores, molecular properties of adsorbed gas and temperature of the reservoir.

To produce CBM, the water must be drawn off first, lowering the pressure so that the methane will desorbs from the coal and then flow to the well bore. As the amount of water in the coal decreases, gas production increases.

Coal beds tend to have low permeability, so that fluids do not flow easily through them unless the reservoirs are stimulated, for example, with hydraulic fracturing.

2.3.1 Coal bed methane resources

Coal bed methane is probably widely spread around the world. Large amounts are known to exist, notably in Australia, Canada, China, Germany, India, Indonesia, Poland, Russia and South Africa (Kuuskraa & Stevens, 2009).

Coal Bed Methane resources are to be found at a deep relatively shallow (usually 200 – 1000 meters depth) but unfeasible to be mined. It is important to notice that not all coal is suitable for methane production. Long-term brown coal fields are poor with methane. Anthracite is marked by high gas concentration but it is impossible to extract it because of the high density and quite low field openness. Methane is usually found in sub-bituminous and bituminous coal, located in the middle between brown coal and anthracite.

The production of gas from CBM reservoirs is unconventional compared to production of sandstone or carbonate reservoirs. Since no entirely reliable technology yet exists to assess how much gas a particular coal bed can yield, the methane gas extraction process is often one of trial and error. CBM exploratory wells are drilled in an attempt to find an economically viable quantity of trapped methane. If the trial is successful, other wells are drilled to produce the methane by bringing it up to the surface, where it is processed and transported through pipelines to the market.

2.3.2 Environmental impact

A high production of coal-bed methane carries with it some technological and environmental difficulties and costs. As water pressure provides the necessary pressure to keep the gas confined within the coal, large volumes of co-produced water are necessary to reduce pressure before gas can be brought to the surface. The amount of water produced varies widely among basins with CBM production, obtaining volumes of water of 4 to 64 m^3 per day and well (US Geological Survey, 2006).

Management of co-produced water is a concern because of the large volumes of water involved and because of the composition of the water. This water, which is commonly saline but in some areas can be potable, must be disposed of in an environmentally acceptable manner.

Common water management strategies include discharge into surface drainages, stock ponds, evaporation ponds and infiltration ponds. In some cases, water is re-injected into subsurface rock formations. In cold regions, it is possible to freeze the water in the winter, collect the salts that separate out, and dispose of or utilize them independently of the water, which can be discharged.

2.4 Gas hydrates

Gas hydrates are gas deposits trapped in ice crystals in permafrost and on the ocean floor. The gas resource contained in hydrates is estimated to be larger than all other sources of natural gas combined, but such gas is not commercially producible with today's technologies.

Globally, the total amount of methane sequestered in these deposits probably exceeds 2,000 Tm^3. Most of this methane is trapped in highly disseminated and/or low saturation methane hydrates that are unlikely to ever be a commercially viable gas source.

3. Main technology improvements to exploit unconventional gas resources

The principal drivers of unconventional gas production have been technological advances in drilling and completion. Many of the technical challenges are common to CBM, tight gas, and shale gas.

3.1 Hydraulic fracturing

During the 1980's, the introduction of massive artificial fractures, known as hydraulic fracturing, was proving successful in the Barnett shale. With the evolution of this hydraulic fracturing technology, the application of a simple blend of water and sand treatments and high pump rates demonstrated the potential for wide scale exploitation at commercial rates. This had the effect in the Barnett shale of doubling initial well rates, with commensurate increases in cumulative recovery.

Hydraulic fracturing (also known as fracking) is a technique used to create fractures that extend from the well bore into rock or coal formations. These fractures allow the oil or gas to travel more easily from the rock pores, where the oil or gas is trapped, to the production well.

Typically, in order to create fractures a mixture of water, proppants (sand or ceramic beads) and some specialty high viscosity fluid additives is pumped down the well at high pressures for short periods of time (hours).

Eventually, the formation will not be able to absorb the fluid as quickly as it is being injected. At this point, the pressure created (up to 500 bar) exceeds the rock strength and causes the formation to crack or fracture.

The sand carried by the high viscosity additives is pumped into the fractures to keep them from closing when the pumping pressure is released. The high viscosity fluid becomes a lower viscosity fluid after a short period of time. Both the injected water and the now low viscosity fluids travel back through the man-made fracture to the well and up to the surface.

Ideally, hydraulic fracture treatment design is aimed at creating long, well-contained fractures for maximum productivity. Fracture migration to the bounding layers is akin to failure of the stimulation job. Problems posed by unconfined fracture growth may include massive fluid loss.

The fluids currently used for fracturing a well are water (90%), mixed with sand (9%) and other additives (1%) like potassium chloride or other friction reducing additives. Sometimes, fracturing is initiated with the pumping of an acid treatment (water with some hydrochloric acid), in order to dissolve part of the rock material, so that the rock pores open and fluid flows more quickly into the well.

During the 2000's, the technology evolved to allow single-trip multi-stage hydraulic fracturing systems and zone isolation, which is driving the cost-effective exploitation of difficult reservoirs.

The location of fracturing along the length of the borehole can be controlled by inserting tough inflatable plugs, also known as bridge plugs, below and above the region to be fractured. This allows a borehole to be progressively fractured along the length of the bore, without leaking fracture fluid out through previously fractured regions. The plugs are inserted into the bore deflated, then expanded to seal off the borehole into a small working region. Piping through the upper plug admits fracturing fluid and proppant into the working region.

3.2 Horizontal /directional drilling

Horizontally drilled wells were first drilled in Texas in the 1930's. The technology has been continuously improved and developed; and by the 1980's, horizontal drilling has become a standard industry practice.

In late 1990's, the application of horizontal drilling enabled more aggressive development as multiple transverse fractures could be placed along a horizontal lateral well-bore.

The technology of horizontal well completions was first adapted for shale gas development to provide increased wellbore exposure to the reservoir area while allowing for a reduced number of surface locations in urban areas. Barnett horizontal wells have laterals ranging from 1000 to more than 3000 meters. A horizontal well may cost three times more than a vertical well, but horizontal drilling provides much more exposure to a formation than does a vertical well.

Thus, horizontal wells can reduce the number of wells needed to developing a gas field. In addition, one can significantly reduce the overall number of well pads, access roads, pipeline routes, and production facilities required, thus minimizing impacts to public and overall environmental footprint.

At the late 1990s, only 40 drilling rigs in the US (6% of total active rigs) were capable of onshore horizontal drilling; that number grew to 519 rigs (28% of active rigs) by 2008.

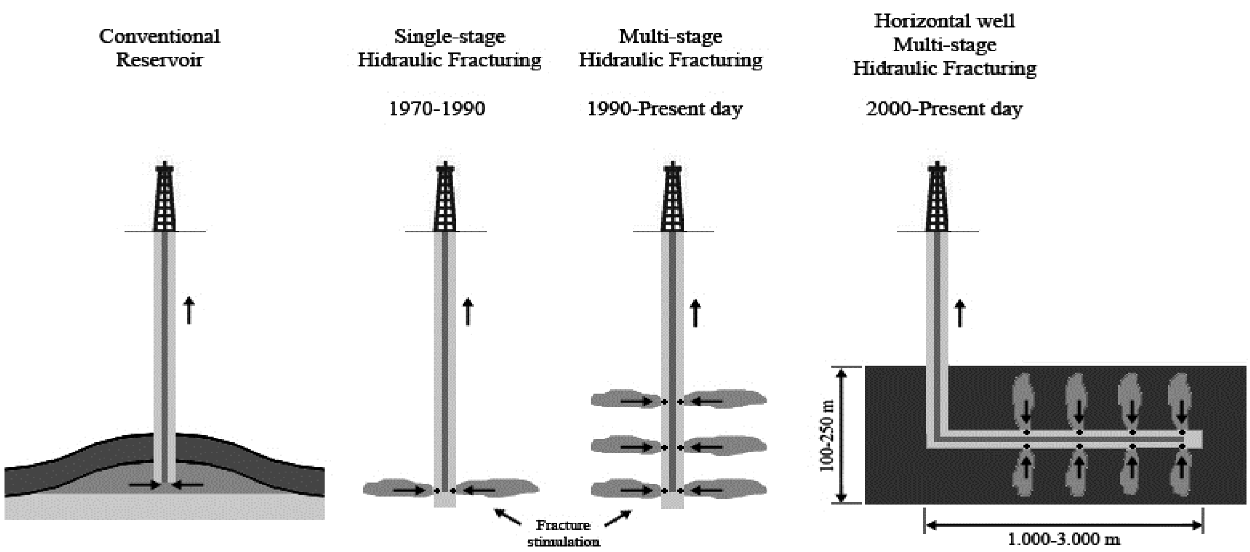


Fig. 2. Main technology improvements to exploit unconventional gas resources.

3.3 Reservoir evaluation, characterization, modeling and sweet- spot detection

A collection of improved exploration and production technologies has aided the development of unconventional gas. Apart from fracking and horizontal drilling, mayor advances have occurred in data acquisition, data processing and integration of seismic data with other geological data.

The tools used by geologist include 3-D seismic, gravity and magnetic surveys, combined with advances in computer power. Ultimately, successful reservoir characterization will result in the ability to accurately develop 3-D representations of these reservoirs. Unconventional gas reservoirs are more difficult to model than conventional gas reservoirs because the flow behavior is transient for much longer periods of time before stabilization. Current logging tools provide measurement of permeability, effective porosity, organic content, gas content, gas saturation, water saturation, clay mineralogy, pressure, temperature, bulk density and other properties.

Understanding of the geo-mechanical and geo-chemical characteristics of the resource rock will add to the ability to locate and characterize natural and artificially created fractures. Developing detection methods for "sweet spot" (areas with natural fracture) is very important to identify where production performance will be most attractive.

At the same time micro seismic technology is used to track and confirm fracture length, width and orientation while carrying out a fracture treatment. This allowed more efficient control of the process, better placement of wells and more economical exploitation.

In parallel, advances in drilling, casing and completion of wells are available through the conventional oil and gas industry. Continuous progress, experience and competition are bringing down the cost of applying these techniques, lowering the economic threshold and making the technology available to more producers.

3.4 Environmental concerns

An environmental concern raised by hydraulic fracturing is the possibility of introducing contaminants into aquifers (Arthur et al, 2008). Hydraulic fracturing does induce new fractures into shale, and can propagate fractures up to 500 - 1000 meters along the bedding plane of a shale formation. The potential for propagating fractures to an overlying aquifer may depend on the depth separating the two.

Frac jobs are always designing to limit the fractures to the height of the gas-producing shale zones, because any fracture propagated to an overlying aquifer could allow water to flow down into the gas-producing portion of the shale, and could significantly hamper gas production.

A frac treatment may pump as much as 10,000 m^3 of fluid for each well. A large proportion of these fluids (60 to 80%) are recovered afterwards by pumping them out of the well. However, fracturing fluids spilled on the ground surface could infiltrate downwards to shallow groundwater. This could pose a risk to superficial aquifers composed of permeable sand.

Unconventional gas shale's resources are typically deeper than coal bed methane formations and are often geologically isolated from drinking water aquifers. The environmental concern may be higher in the shallow coal bed methane formations because these shallow coal beds can also contain high quality water which could meet drinking water standards.

A properly designed and cased well will prevent drilling fluids, hydraulic fracturing fluids, or natural gas from leaking into the permeable aquifer and contaminating groundwater.

Although fracturing operations related to oil and gas production are exempted from the US Safe Drinking Water Act, the item remains highly controversial.

4. The expansion of non conventional gas in North America

4.1 Shale gas basins

4.1.1 The expansion of US Gas Shale production

The extraction of natural gas from shale formations has been occurring in parts of the United States since earliest years of gas development. However, many of these early wells were never able to produce a marketable quantity of natural gas.

Shale gas is actually the fastest growing energy sector in US (US Department of Energy, 2009), driven by the technology improvements and the presence of big shale basins.

The development of shale gas plays has become a "game changer" for the U.S. natural gas market.

In 1996, shale gas wells in the United States produced 8 bcm; by 2006, production raised to 30 bcm, 5.9% of US gas production.

By 2005 there were 14,990 shale gas wells in the US. A record 4,185 shale gas wells were completed in 2007.

In 2008, US Shale gas production was 55 bcm, making up more than 10% of total US production of dry gas

The proliferation of activity into new shale plays has increased shale gas production in the United States to 138 bcm in 2010, or 23% of U.S. dry gas production.

Shale gas reserves have increased to about 1 700 bcm by year-end 2009, when they comprised about 21 percent of overall U.S. natural gas reserves, now at the highest level since 1971. This number does still not counts estimated gas resources in new areas.

4.1.2 Main US gas Shale Basins

Most of the natural gas containing Devonian shale in the US is located around the Appalachian Basin. Devonian shales are formed from the mud of shallow seas that existed about 350 million years ago, during the Devonian period of the Paleozoic era.

The two big Shale Basins are the Barnett Shale in Texas and the Marcellus Shale, but there is also strong growth in Fayetteville and Haynesville in particular, with modest growth in several others. In Canada, main gas shale areas are Horn River and Montney, both in British Columbia.

The seven most promising shale gas plays in North America - referred to by the industry as the 'Magnificent Seven'- are likely to double output by 2020 (US Energy Information Administration, 2011).

Main gas shale formations in US and Canada
Barnett (Texas)
Fayetteville (Arkansas)
Haynesville (Louisiana)
Woodford (Oklahoma)
Marcellus (WV, PA, NY)
Montney (Canada)
Horn River (Canada)

Table 1. Main gas shale formations in US and Canada (the magnificent seven).

The big seven gas shales in North America (USA and Canada) have around 20 Tm^3 of recoverable resources of natural gas, which represent about a 12% of the total estimated gas resources of these fields (Kuuskraa & Stevens, 2009).

4.1.3 The Barnett Shale

The relatively recent focus on shale gas development goes back 20 years, and is highlighted by the success achieved in the Barnett shale in Texas.

The Barnett Shale is a large natural gas reserve encompassing more than 12,000 km^2 and covering at least 17 counties in Fort Worth Basin, Texas. This layer of organically rich sediment ranges from 120 to 240 meters thick and lies about two kilometers below the surface. Experts believe that the Barnett Shale may be one of the largest onshore natural gas fields in the United States, containing around 1,000 bcm of recoverable resources of natural gas.

Mitchell Energy drilled the first gas well in the Barnett Shale in 1981. Large scale hydraulic fracturing was first used in the Barnett in 1986; likewise, the first Barnett horizontal well was drilled in 1992. Actually, there are more than 10,000 natural gas wells, and the Barnett is now the largest producing gas field in the US, and currently produces more than 6% of US natural gas production.

4.1.4 The Marcellus Shale

The Marcellus Shale is a formation covering 250,000 km^2 beneath much of Ohio, West Virginia, Pennsylvania and New York (an area equivalent to half Spain). These states contain also some of the most densely populated areas in the United States. Marcellus has the advantage of being close to the north-east US gas market

The first Marcellus gas production from the well began in 2005. Early estimates indicate that the Marcellus Shale might contain 50 Tm^3 of natural gas resources.

Using some of the same horizontal drilling and hydraulic fracturing methods that had previously been applied in the Barnett Shale, perhaps up to 10% of that gas (5,000 bcm) might be recoverable. That volume of natural gas would be enough to supply the entire United States for about ten years.

Since 2006, when the big potential of the Marcellus was first suspected, many landowners are being approached with offers to lease their land, and a lot of companies are actively drilling or leasing Marcellus Shale properties, so in several years, Marcellus could be producing as much gas as Barnett shale.

A similar process is starting to occur at Fayetteville and Haynesville basins, so we can expect a strong growth of US shale gas production at least for the next 3 to 5 years.

However, the production decline rate of a shale well is much higher than those of a conventional gas wells, which means than continuous drilling is needed to maintain plateau production.

4.2 Tight gas basins

Tight gas is today the largest source of unconventional gas at US, with an annual production around 160 – 180 bcm, that represents about a 30% of total US production of dry gas, with more than 100,000 tight producing wells (US Energy Information Administration, 2011). In Canada, tight gas represents about 15% of gas production.

Tight gas wells started being produced not by major oil companies, for the most part, but by small, independent operators who focus on recovering production from old fields.

First large scale production of tight sands was developed in the 1970's in San Juan Basin. The San Juan Basin, located in north-western New Mexico and south-western Colorado, is a predominately tight basin with 13,000 tight producing wells.

Rapid progress in fracturing techniques led to the launch of tight gas production in the United States, from 35 bcm in 1995 to more than 150 bcm since 2007.

Most of the US's tight-gas proved reserves are in the Rocky Mountain region. Total recoverable resources at US are estimated around 9 Tm^3.

4.3 Coal Bed Methane basins

4.3.1 The expansion of US Coal Bed Methane production

To date, CBM industry has been developed only in United States, Australia, Canada and Colombia.

In United States, coal beds were primarily developed through programs led by the Department of Energy. The Crude Oil Windfall Profits Act (1980) provided tax incentives to develop unconventional fuels including CBM. The definition of deregulated natural gas addressed in this Act included occluded gas - naturally occurring natural gas released from entrapment from the fractures, pores, and bedding planes of coal seams. Also specified were gas produced from deep (greater than 3,000 m), high cost natural gas reservoirs, natural gas dissolved in an over-pressured brine and natural gas produced from Devonian shale. Coal Bed Methane production rapidly increased from 5 bcm in 1990 to 27.1 bcm in 1995 and in 2008 it reached 56 bcm, which accounts for nearly 10% of U.S. gas production. The Wasatch Plateau, Utah, and the Powder River Basin, Wyoming and Montana, are two of the newest, most productive areas of coal-bed methane activity in the United States.

In Australia, CBM production started in 1998 replacing ageing conventional gas fields, due to Government incentives for gas-fired power. In 2008, CBM accounted for around 7% of Australian gas production.

4.3.2 Main US Coal Bed Methane basins

The two big CBM basins are the Powder River Basin in Wyoming and Montana, and San Juan Basin in Colorado and New Mexico.

According to the Potential Gas Committee estimated data, CBM basins in US have around 4.5 Tm^3 of recoverable resources of natural gas.

a. The Powder River Basin CBM

The Powder River Basin is located in north-eastern Wyoming and south-eastern Montana. It is an area of approximately 55,000 km^2 that is underlain by many coal seams. The basin extends over 400 km from Douglas, Wyoming, in the south to Forsyth, Montana, in the north. Extraction of methane gas from the coal seams that underlie the Powder River Basin began in Wyoming in the late 1980s and in Montana in the late 1990s (US Geological Survey, 2000). With advances in technology, development and production of CBM has been increasing substantially since the mid 1990s. The basin is characteristic because of the extraordinary thicknesses of individual seams, between 15 and 67 m; most of this resource is at a depth of 760 m or less.

b. San Juan Basin CBM.

The San Juan basin is approximately 23,300 km^2 in north western New Mexico and south-western Colorado. It is the leading producer of coal bed gas in the world.

Conventional gas exploration began in the early 1900s. The first well was drilled in 1901, but the first commercially successful well was drilled in 1921. Thousands of wells have been drilled in the San Juan basin since then.

CBM development started in earnest in the late 1980s, in the Fruitland Formation of the Northern San Juan Basin. The basin has experienced highly successful CBM production because of the favorable characteristics of the coal seam related to thickness, permeability, gas content, depth, and coal rank in a large area.

5. Unconventional gas production at the United States and EIA projections

Tight gas was the first unconventional production gas developed, and is today the largest source of unconventional gas at U.S. However, shale gas production in the United States grew from 20 to 100 bcm over the 2006-2010 period, and is actually the fastest growing energy sector in U.S.

In 2010, natural gas production in United States was around 590 bcm, including 186 bcm of tight gas (31% of US production), 93 bcm of shale gas (16%) and 51 bcm of coal bed methane (9%).

The IEA Annual Energy Outlook (2011) estimates that US natural gas production will grow from 590 bcm in 2009 to 740 bcm in 2035 (IEA reference case). The increase in natural gas production from 2009 to 2035 results primarily from continued exploration and development of shale gas resources, and shale gas is the largest contributor to production growth.

Shale gas production could reach 350 bcm in 2035 (47% of total U.S. production, nearly triple its 16% share in 2009). Only two years ago, the reference scenario of IAE considered a shale gas production of “only” 130 bcm in 2030.

The projections for tight sands and coal bed methane deposits remains more stable, around 170 and 50 bcm per year, respectively, during all the period [Figure 3].

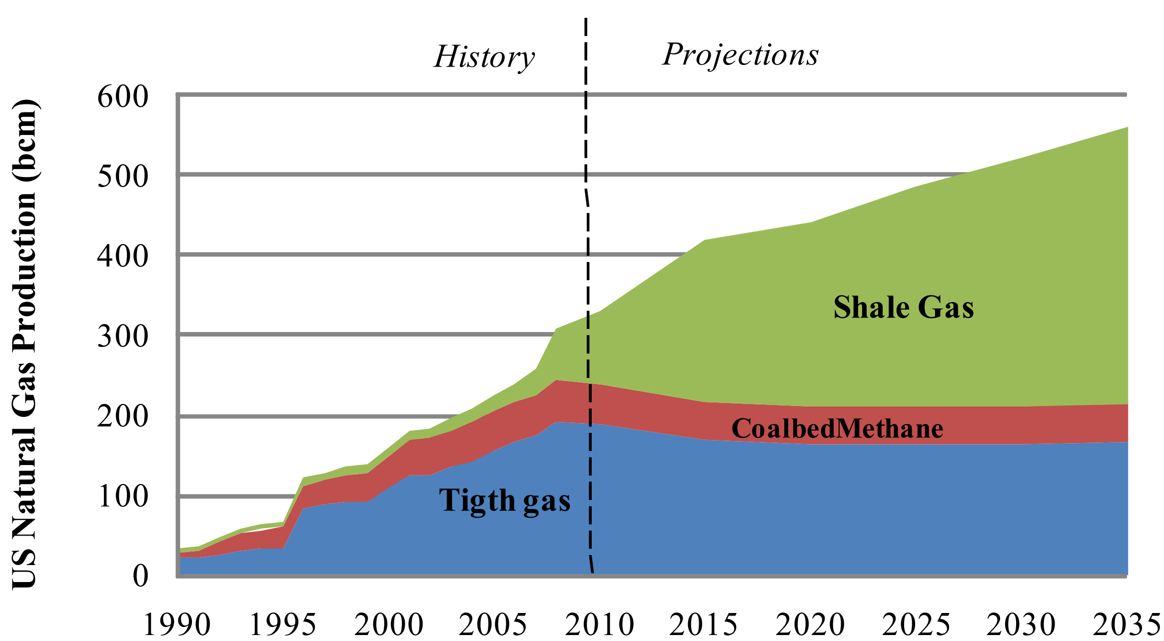


Fig. 3. US Unconventional Gas Production and Projections to 2035. Source: US Energy Information Administration, 2011.

The Energy Information Administration estimates that the US has more than 47 Tm^3 of technically recoverable natural gas, including 6 Tm3 of proved reserves (the discovered and economically recoverable fraction of the original gas in place). Technically recoverable unconventional gas (shale gas, tight sands, and coal bed methane) accounts for 60% of the onshore recoverable resource. At the US production rates for 2010 the current recoverable resource estimate could provide enough natural gas to supply the US for the next 75 years.

The proved reserves of shale gas in North America and the existing LNG infrastructure create the potential of LNG exports to Europe or Asia, which can help Europe to diversify its natural gas supply sources.

However, the high decline rates of unconventional gas will also require continuous investment in new wells to maintain production. The drilling activity is very sensitive to the price of gas. Since June 2008, the drop in natural gas prices have weaken the incentive to drill, but unconventional gas seems to maintain competitive even at low gas prices.

6. Estimations of recoverable resources and production for unconventional gas

Although understanding of the scale of global unconventional gas resources is improving, the complex issues related to unconventional gas resources mean that future production projections are subject to a large degree of uncertainty, particularly in regions where little or no such production has been undertaken to date.

Unconventional gas resources, although believed to be widespread, have not as yet been quantified on a national basis for most countries, apart from the United States and a few other countries.

Due to his early state of play, studies about unconventional gas do not have information about “proved reserves” of unconventional gas. Instead, they generally use estimates about the natural gas resource base, and technically /economically recoverable resources:

- **The natural gas resource base** - The broadest classification of natural gas estimates is generally termed the natural gas resource base. The total natural gas resource base includes the entire volume of natural gas contained and trapped in the earth, before any is extracted and produced.
- **Economically recoverable resources** - Economically recoverable resources are those natural gas resources for which there are economic incentives for production; that is, the cost of extracting those resources is low enough to allow natural gas companies to generate an adequate financial return given current market conditions. However, it is important to note that economically unrecoverable resources may, at some time in the future, become recoverable, as soon as the technology to produce them becomes less expensive, or the characteristics of the natural gas market are such that companies can ensure a fair return on their investment by extracting this gas.
- **Reserves** - Those resources discovered, technically and economically recoverable. In general, reserves can be broken down into two main categories - proved reserves, and other reserves.

- **Proved Reserves** - Proved reserves are those reserves that geological and engineering data indicate with reasonable certainty to be recoverable today with current technology and under current economic conditions.

6.1 World projections of the International Energy Agency (World Energy Outlook 2011).

In the Gas Scenario of the IEA World Energy Outlook 2011, the total gas production grows from an estimated 3.3 Tm^3 in 2010 to 5.1 Tm^3 by 2035, an increase of more than 50%, and more than double gas production in 2000. The average annual growth in gas production is 2% from 2008 to 2020, and then moderates to around 1.6% for the remainder of the Outlook period.

Natural gas production increasingly comes from unconventional sources. Unconventional gas production meets more than 40% of the increase in demand over the period: unconventional gas output worldwide will rise from 367 bcm in 2007 and is projected to reach 1200 bcm in 2035. As a result, the share of unconventional gas in global gas production is expected to rise from 12% in 2008 to nearly 25% in 2035.

Most of the increase in unconventional gas production in the EIA Gas Scenario comes from shale gas and CBM. In particular, the share of shale gas in global gas production reaches 11% in 2035, while CBM reaches 7% and tight gas 6%.

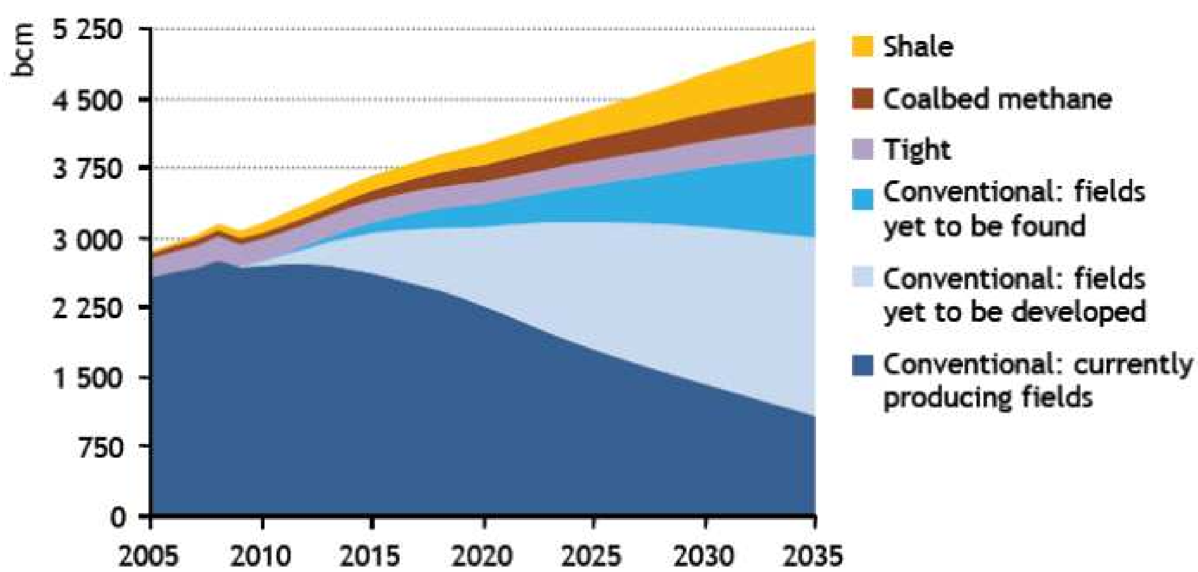


Fig. 4. Natural gas production by type. Source: IEA Energy Outlook 2011.

The natural gas resource base is vast ant widely dispersed geographically, with conventional recoverable resources equivalent to over 120 of current global consumption, while total recoverable resources could exceed 250 years, according to IEA.

Unconventional gas resources, comprising shale gas, tight gas and coal bed methane are estimated to be as large as conventional resources. IEA analysis suggests than plentiful volumes can be produced at costs similar to those in North America (between 3 \$/mmBtu and 7 \$/mmBtu).

Unconventional gas production is currently concentrated in the United States and Canada. By the year 2035, unconventional gas also reaches a significant scale in China (CBM and shale), Russia (tight gas), India (shale) and Australia (CBM).

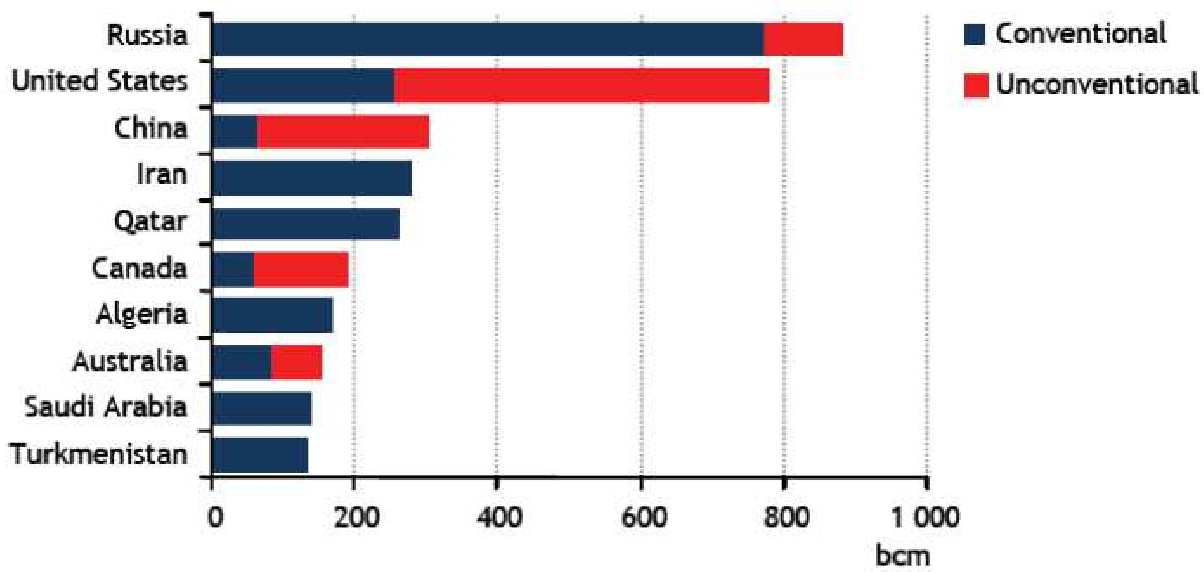


Fig. 5. Largest gas producers by type in 2035. Source: IEA Energy Outlook 2011.

6.2 Assessment of world shale gas resources by US Energy Information Administration (2011)

To gain a better understanding of the potential of international shale gas resources, EIA commissioned an external consultant, Advanced Resources International, Inc. (ARI), to develop an initial set of shale gas resource assessments, excluding tight gas and CBM (EIA, 2011).

Although the shale gas resource estimates will likely change over time as additional information becomes available, the report shows that the international shale gas resource base is vast. The initial estimate of technically recoverable shale gas resources in the 32 countries examined is 163 Tm^3. Adding the U.S. estimate of the shale gas technically recoverable resources of 24 Tm^3 results in a total shale resource base estimate of 187 Tm^3 for the 33 countries assessed, as shown in Table 2.

To put this shale gas resource estimate in some perspective, world proven reserves of natural gas as of January 1, 2010 are about 188 Tm^3 and world technically recoverable gas resources are roughly 453 Tm^3, largely excluding shale gas. Thus, adding the identified shale gas resources increases world technically recoverable gas resources by over 40% to 640 Tm^3.

Russia and Central Asia, Middle East, South East Asia, and Central Africa were not addressed by this report. This was primarily because there was either significant quantities of conventional natural gas reserves noted to be in place (i.e., Russia and the Middle East), or because of a general lack of information to carry out even an initial assessment.

Technically Recoverable Shale Gas Resources (Tm³)		
North America	United States	24,4
	Canada	11,0
	Mexico	19,3
	Total North America	**54,7**
South America	Argentina	21,9
	Brazil	6,4
	Chile	1,8
	Paraguay	1,8
	Bolivia	1,4
	Uruguay	0,6
	Colombia	0,5
	Venezuela	0,3
	Total South America	**34,7**
Asia	China	36,1
	Australia	11,2
	India	1,8
	Pakistan	1,4
	Total Asia	**50,5**
Africa	South Africa	13,7
	Libya	8,2
	Algeria	6,5
	Tunisia	0,5
	Morocco	0,3
	Western Sahara	0,2
	Mauritania	0,0
	Total Africa	**29,5**
Europe	Poland	5,3
	France	5,1
	Norway	2,4
	Ukraine	1,2
	Sweden	1,2
	Denmark	0,7
	U.K.	0,6
	Netherlands	0,5
	Turkey	0,4
	Germany	0,2
	Lithuania	0,1
	Total Europe	**17,6**
Total	**Total 33 countries**	**187,0**

Table 2. Technically Recoverable Shale Gas Resources. Source: AIE. World Shale Gas Resources: An Initial Assessment, 2011. Note: Only 33 countries are covered by the report. In particular, Russia is not included in the assessment.

6.3 Unconventional gas exploration outside US

The recent US success in developing shale gas has prompted other countries to consider its own unconventional gas potential.

Most of the mayor oil and gas companies are actually making investment in US unconventional gas assets, in order to have access to these gas resources, but also to acquire technical exploration and production experience, and transfer this experience to other regions. The extent to which the boom in unconventional gas production can spread to other countries remains highly uncertain.

In China, India, Australia and Southeast Asia, unconventional gas might begin to make inroads into the supply mix in 5 to 10 years' time. This is probably a conservative projection, and there is potential to higher increases.

6.3.1 China

Shale gas and CMB looks promising in China, although appraisal is still at a very early stage. China currently is not producing shale gas, but it has very similar geological conditions to the US so could boast similar shale gas development potential. In fact, Chinese shale gas resource could be up to 26 - 36 Tm^3 of recoverable gas. Assuming the government supports the industry, China's unconventional resources could begin to have an impact from the middle of the next decade.

6.3.2 Europe

Shale gas exploration in Europe is in its infancy. As a consequence, little is known about Europe’s ultimate potential.

There are some potentially major regional shale gas plays in Europe plus a number of others with local potential, but they don’t seem equivalent to the American scale. Most promising are the Baltic Depression (mainly in Poland, also in Lithuania), Lower Saxon basin (Northwest Germany) and several areas in UK and Netherland, Sweden and Austria. In Ukraine, the shale gas potential exists in the Lublin Basin and the Dnieper-Donets Basin.

European governments, particularly in Eastern Europe (Poland, Ukraine), see an opportunity to reduce dependence on Russian gas imports.

Poland is seen as the most promising country for shale gas development in Europe, thanks to favorable geological and regulatory environments, and it leads the way to shale gas in Europe. Poland has already issued 221 licenses for exploration of hydrocarbons, of which 63 have been issued for shale gas. Exploration work covers 11% of Poland’s area. Lane Energy Poland Sp. was the first company to start drilling in June 2010. Reliable information on the resource base will be probably available in four or five years.

According to the Polish Kosciuszko Institute, Polish shale gas exploration and production costs are 50% higher than in the US; however, gas prices could still be lower than those under long term oil-indexed contracts with Russia.

Some good news may also come from other countries, like Spain, were preliminary studies carried out in northern Spain estimates the presence of about 185 bcm of shale gas in the Gran Enara field in Alava.

By contrast, in **France** environmentalists have been campaigning against the fracking after a few of shale drilling licenses were awarded in the south of France and around Paris. In July 2011, France has approved to outlaw the fracking techniques, because the environmental concerns.

Russia and North African countries could also have important unconventional gas resources, but given the fact that Russia has the World large reserves of conventional natural gas, there may not be sufficient incentive to identify or exploit unconventional gas resources in the near term.

7. Economic impact on gas markets

Natural gas markets are smaller and less mature than oil markets. At present, trade is centered in three distinct regional gas markets — North America, Europe and Asia). Each region has a different market structure resulting from the degree of market maturity, the sources of supply, the dependence on imports and other geographical and political factors. Importantly, these regional markets set natural gas prices in different ways.

- In general, the U.S. has gas-on-gas competition. Robust spot and derivatives markets have developed in, with prices set by the forces of supply and demand.
- The European market relies more heavily on long-term contracts with price terms based on a mix of competing fuels, e.g., fuel oil.
- Asia uses crude oil as a benchmark for natural gas prices and favors long-term contracts. Japan and Korea almost totally dependent on imported LNG. This dependence places a high premium on security of supply and has kept prices in Asia high relative to other regions.

This regionalized and varied structure of natural gas markets stands in contrast to the global oil market. The physical characteristics of oil — a very high energy density at normal conditions of temperature and pressure — make it readily transportable over long distances, at moderate cost. This has allowed the development over time of a global oil market, where multiple supply sources serve markets at transparent spot prices.

In comparison, the physical characteristics of natural gas constrain transportation options. Unlike oil, transportation costs — whether for pipeline gas or liquefied natural gas (LNG) — constitute a significant fraction of the total delivered cost of natural gas (MIT, 2010).

7.1 US market decoupling from oil market

The rapid development of unconventional gas resources in the Unites States and Canada, particularly in the last three years, has transformed the gas market in North America.

Marginal cost of unconventional sources have fallen steeply, at a wellhead cost between 3 and 5 $/mmBtu. An additional benefit is that gas is found in areas with much of the necessary pipeline infrastructure already in place. Many of these areas are also proximal to big population centers thus potentially facilitating transportation to consumers.

This supplement to supply, combined with weak gas demand following the economic crisis, has led to a drop in US gas prices from 13.68 $/mmBtu in July 2008 to prices under 5 $/mmBtu in 2009.

The energy parity between oil and gas prices seems to be already broken at US markets since January 2009: Oil prices have hovered around 100 $/barrel for much of 2010 and 2011 while the U.S. Henry Hub (HH) price has been consistently below 5 $/mmBtu (Figure 6).

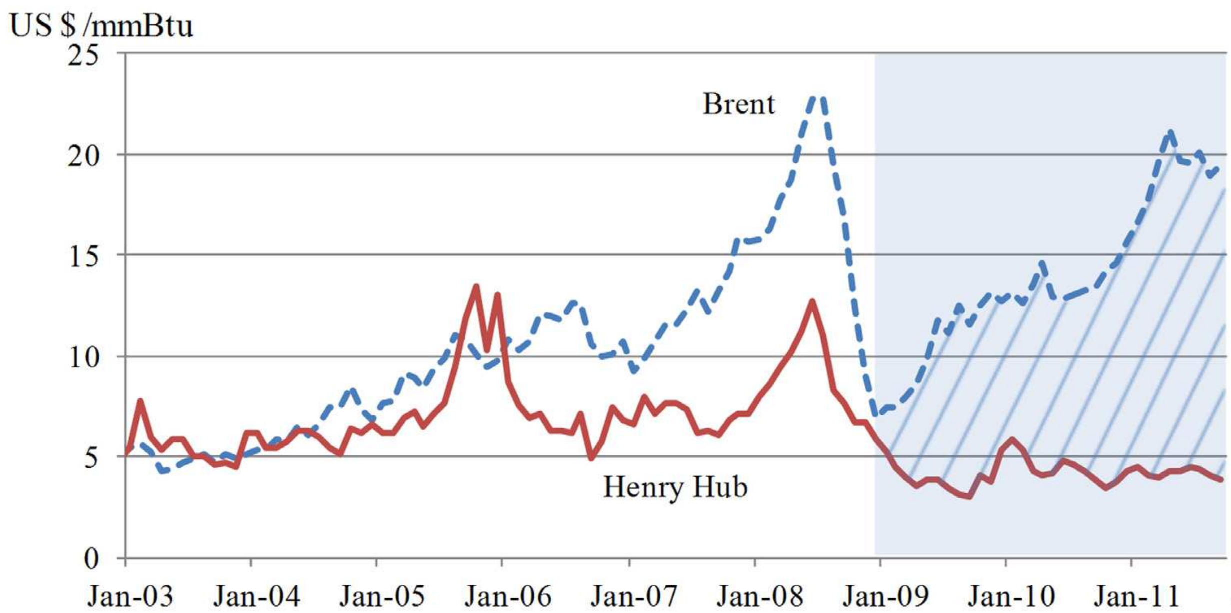


Fig. 6. Evolution of oil (Brent) and U.S. gas prices (Henry Hub). The energy parity between oil and gas prices seems to be already broken since 2009.

The development of unconventional gas resources means that North America gas production may be sustainable at current levels for decades.

In 2008, the trend of increasing import volumes stalled as net imports only met about 13% of overall US natural gas consumption in 2008, which is the lowest percentage since 1997.

A first consequence is that North American gas market has fewer needs to compete for available global supplies, as relatively low prices are expected to discourage imports of LNG, and can also delay the construction of gas pipelines from Alaska.

In contrast, oil prices maintain stronger than gas prices in the economic downturn scenario. While technological advances in finding and producing oil have made it possible to bring oil to the surface from more remote reservoirs at ever increasing depths, the total finding and lifting costs of new oil wells have increased sharply in recent years. Also, new oil discoveries can be insufficient to replace the depletion of existing ones.

When the world economy rebounds, oil global demand will put pressure on oil prices, and oil prices will rise faster than gas prices on the next decade (Stevens, 2010).

7.2 Decoupling US gas market from European gas markets

The European market still has not been affected by the rise of U.S. unconventional gas.

As Figure 7 shows, Europe currently offers prices in 2010 that are more than double those in the U.S. The UK's Natural Balancing Point price (NBP) has been in the 8 to 10 $/mmBtu

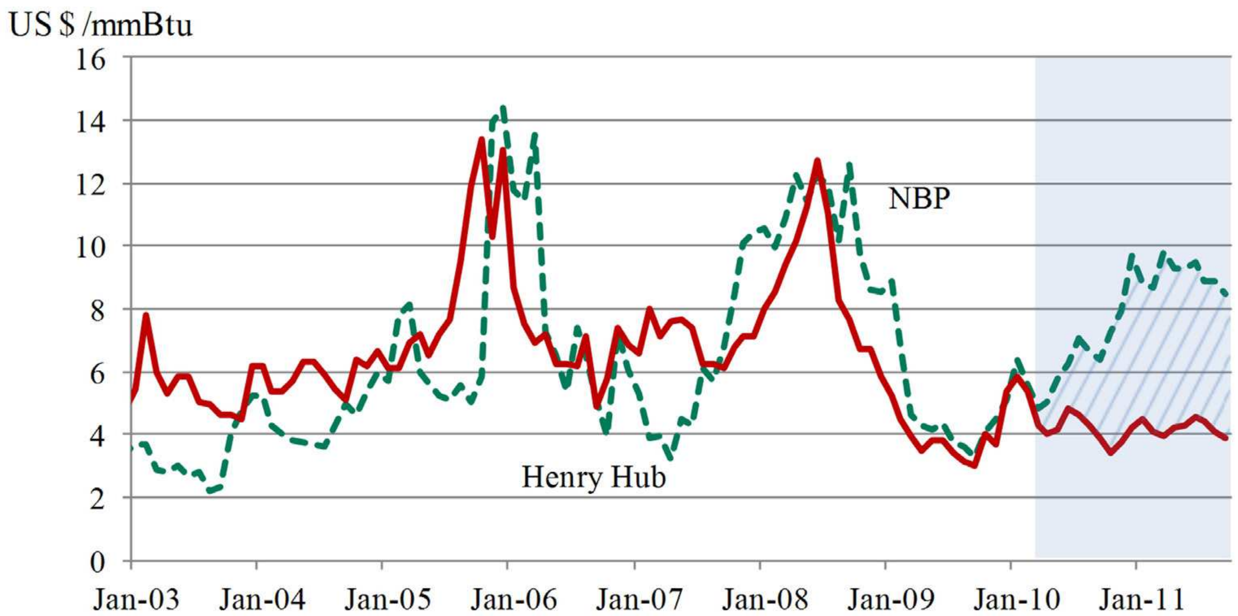


Fig. 7. Evolution of natural gas prices between U.K. market (NBP) and U.S. market (Henry Hub). Decoupling of price is observed since January 2010.

range for the first nine months of this year, while Henry Hub (HH) price has been consistently below 5 $/mmBtu.

Also long term contract (oil-linked) in continental Europe have been at an average premium of $1.60/mmBtu over NBP during 2011.

The global economic and financial crisis, which began in late 2008, has significantly depressed European gas demand. In addition to that, substantial new LNG supply is coming on stream during 2009-10. Even with a depressed demand, LNG imports to Europe increased more than 10% in 2009, particularly to the UK market.

The substantial short term supply gas surplus in Europe is increasing the pressure for change in the price-setting mechanism of European oil-linked long term gas contracts (Stern, 2009). Short term prices at market hubs are at around half of oil-linked levels in 2009.

The premium price paid for LNG in Europe and Asia over gas prices North America has prompted some companies to plan to turn US under-utilized LNG receiving terminals into export plants by building liquefaction trains. This would be attractive if the actual gap between US and Europe /Asian gas prices, that compensate the transport cost, continue in the next years.

While it seems unlikely to avoid oil – price indexation for Europe and Asian long term gas contracts, they will likely start to reflect the gas bearish conditions with decreasing indexation slopes. Buyers across Europe push for a move to hub-based pricing, which will increase price volatility and could push the price level down towards the UK's NBP price. The change could be more rapid if some unconventional fields start to develop in Europe.

8. Conclusions

There are abundant supplies of natural gas in the world, and many of these supplies can be developed and produced at relatively low cost. Consequently, natural gas is set to play a key role in meeting the XXI century world's energy demand and his production is likely to continue to expand.

According to IEA, the total gas production will grow a 50% by 2035. Unconventional gas accounts for 40% of the increase in global supply, with new non-US producers emerging.

In total, unconventional gas resources could add between 60 to 250% to world gas reserves.

Main potential is in US, Canada, China, Russia and Australia.

In North America, shale gas development over the past decade has substantially increased assessments of resources producible at modest cost. The pace of shale technology development has been very rapid over the past few years.

The emergence of shale gas as a potentially major energy resource can have important strategic implications for geopolitics and the energy industry:

- Shale gas resources in the United States will keep natural gas prices relatively low for an extended period of time. Longer periods of lower gas prices will likely result in additional demand for gas from the power generation sector.
- Global conventional natural gas resources are concentrated geographically, with 70% in three countries: Qatar, Iran and Russia. Unconventional supplies could provide a major opportunity for diversification and improved security of supply in some parts of the world.

In favor	Barriers
• Large potential gas resources worldwide. • Technology is already competitive in USA. Major oil and gas companies will contribute to spread the technology around the world. • China, India and Australia have large unconventional resources and can be next countries to develop them in a large scale • It is possible to locate new reservoirs in OCDE countries (close to consumption) • In Europe exploration is underway in some countries (Poland, Ukraine).	• Limited knowledge of location and volume of gas reservoirs. • Incertitude about extraction costs outside USA, and rate of decline of wells. • Lack of interest of some exporting countries (mainly Russia). • Environmental concerns (example: France) • Low gas demand and gas prices will difficult the financing of new projects

Fig. 8. Main factors affecting the development of unconventional gas resources.

- Shale gas exploitation can benefit some European countries, but it will not significantly reduce dependency on gas imports from Russia, at least in short term. However, unconventional gas may create pressure on gas exporters to move away from oil-price indexation.

However, there are also a number of key uncertainties:

- Limited knowledge of location and volume of unconventional gas reservoirs.
- Environmental concerns, mainly in Europe.
- Incertitude about extraction costs outside US, and rate of decline of wells. Because of the shale gas revolution, there are now huge uncertainties for investors at all stages of the gas value chain.

9. References

Al-Husseini, *"Long-Term Oil Supply Outlook: Constraints on Increasing Production Capacity"*, presented at Oil and Money Conference, London, October 2007, Available: http://www.boell-meo.org/download_en/saudi_peak_oil.pdf

Aleklett, K, *"Peak Oil and the Evolving Strategies of Oil Importing and Exporting Countries"*. OECD International Transport Forum. Discussion Paper Nº 2007-17, Dec, 2007

Arthur J.D.; Bohm B and Layne M., *"Hydraulic Fracturing Considerations for Natural Wells of the Marcellus Shale"*, presented at Ground Water Protection Council Annual Forum, Cincinnati, Ohio. September 2008.

BP Statistical Review of World Energy. June 2011. Available: http//www.bp.com/statisticalreview

International Energy Agency (IEA). World Energy Outlook 2011.

International Energy Agency (IAE). Golden Age of Gas 2011 (special report)

Kuuskraa V.A. and Stevens S.H., *"World Gas Shales and Unconventional Gas: A Status Report"*, presented at United Nations Climate Change Conference, Copenhagen, December 2009.

Massachusetts Institute of Technology, *Study on the Future of Natural Gas*, 2010

Stern J., *"Continental European Long-Term Gas Contracts: is a transition away from oil product-linked pricing inevitable and imminent?"*, Oxford Institute for Energy Studies, September,2009.

Stevens, Paul; *"The Shale Gas Revolution. Hype and Reality"*. Chatham House Report, 2010

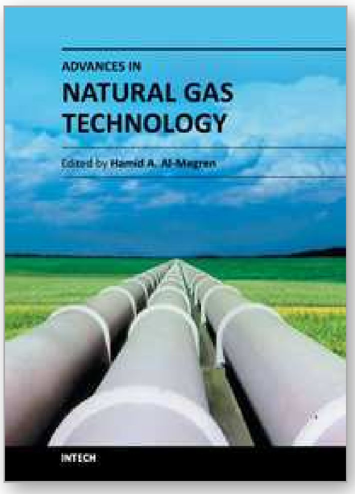
U.S. Department of Energy, *Modern Shale Gas Development in the United States: A Primer.*, April 2009. Available: http// www.netl.doe.gov/

U.S. Geological Survey. November 2000. *Water Produced with Coal-Bed Methane*

U.S. Geological Survey. November 2006. *Coalbed Methane Extraction and Soil Suitability Concerns in the Powder River Basin, Montana and Wyoming*

U.S. Energy Information Administration (EIA). Annual Energy Outlook 2011 with projections to 2035. April 2011. Available: www.eia.doe.gov

U.S. Energy Information Administration. *World Shale Gas Resources: An Initial Assessment of 14 Regions Outside the United States*. April 2011



Advances in Natural Gas Technology

Edited by Dr. Hamid Al-Megren

ISBN 978-953-51-0507-7
Hard cover, 542 pages
Publisher InTech
Published online 11, April, 2012
Published in print edition April, 2012

Natural gas is a vital component of the world's supply of energy and an important source of many bulk chemicals and speciality chemicals. It is one of the cleanest, safest, and most useful of all energy sources, and helps to meet the world's rising demand for cleaner energy into the future. However, exploring, producing and bringing gas to the user or converting gas into desired chemicals is a systematical engineering project, and every step requires thorough understanding of gas and the surrounding environment. Any advances in the process link could make a step change in gas industry. There have been increasing efforts in gas industry in recent years. With state-of-the-art contributions by leading experts in the field, this book addressed the technology advances in natural gas industry.

InTech Europe
University Campus STeP Ri
Slavka Krautzeka 83/A
51000 Rijeka, Croatia
Phone: +385 (51) 770 447
Fax: +385 (51) 686 166
www.intechopen.com

InTech China
Unit 405, Office Block, Hotel Equatorial Shanghai
No.65, Yan An Road (West), Shanghai, 200040, China
中国上海市延安西路65号上海国际贵都大饭店办公楼405单元
Phone: +86-21-62489820
Fax: +86-21-62489821