mirova
Responsible Investing

//////// Research paper ////////

SHALE GAS AND UNCONVENTIONAL GAS

NEW RESOURCES, NEW CHALLENGES

Ladislas Smia
SRI Analyst

Ladislas Smia
SRI Analyst

INTRODUCTION

November 2012

Alternative solutions to traditional energies are progressively emerging in light of high energy prices. Shale gas and, more generally, unconventional gas are amongst those set to play an increasing role in world energy supply, mainly due to the importance of reserves in numerous regions.

Up to now, unconventional gas has essentially been developed in North America in response to the reduced production of conventional gas. Exploitation of these resources was possible due to innovations from American companies (notably combining horizontal drilling and hydraulic fracturing techniques).

In North America and Europe, such techniques have sparked numerous controversies regarding their environmental and social impacts. Water pollution, land use and impact on climate change are the most frequently emphasised issues. Despite these controversies, the American example, which ultimately separated oil and gas prices, led to a profound change in the balancing of energy prices and is now being seriously considered by politicians in many countries.

The aim of this document is to provide an insightinto the environmental and social impacts of the exploitation of these resources.

THE EXTRA-FINANCIAL RESEARCH POSITION
ON UNCONVENTIONAL GAS

Following the analysis of various environmental and social impacts associated with the exploitation of unconventional gas, we hold the following position:

- **In general, we consider gas, as a substitute for more pollutant energy sources such as coal or fuel oil, to be a transitional solution in the fight against climate change, depending on the country.**

  In the special case of unconventional gas, we believe that this resource can be used as a substitute for more pollutant sources, for instance:
  - for coal in electricity production
  - for imports originating from countries with less strict environmental regulations
  - for modes of transport that impact heavily on the environment, such as leaks in pipelines and high energy consumption of liquefied natural gas (LNG).

  Using unconventional gas can therefore reduce greenhouse gas emissions.

- **However, exploitation of unconventional gas presents additional risks with regard to traditional fields,** e.g. the risk of water table contamination, the issue of land use, and greater climatic impact than that of conventional gas. On the basis of current knowledge, we believe that measures taken by operators to limit these impacts must be examined case by case.
  - In the most favourable cases (exploitation in sparsely populated areas, exploitation in a sufficiently controlled and regulated area, use of the best available techniques, the operator's good safety reputation), we believe that these additional risks can be sufficiently monitored. In these cases, for unconventional gas we hold a position similar to that of conventional gas.
  - In other cases (exploitation in a densely populated area, lack of transparency in the techniques used, reservations about control systems, poor safety reputation), using these resources will lead to a negative bias in the environmental and social analysis of the operators involved.

- **This position will be followed up over time in order to:**
  - take into account the most recent research on local impacts, particularly on water resources
  - ensure that the development of these resources (unconventional as well as conventional gas) makes a transition towards a more sustainable energy mix without hampering the development of renewable energies and energy efficiency solutions.

In our opinion, these last two solutions must remain a top priority and are consequently strongly favoured in our analyses.

QUESTIONS AND ANSWERS
ON UNCONVENTIONAL GAS

What are unconventional gas resources?

Even though there is no official definition of unconventional gas resources, they are generally defined as any type of gas which requires specific techniques for underground extraction.

Today there are three types of unconventional gas:

➜ **Tight gas**

This gas is very similar to conventional gas apart from the fact that the reservoir rock that contains it is practically impermeable, making the exploitation of this resource more difficult.

➜ **Shale gas**

Located in a source rock as it has yet to migrate to a 'reservoir rock' unlike conventional gas or tight gas. In almost all cases, this source rock is even less permeable than tight gas.

➜ **Coalbed methane (CBM)**

This gas is similar to shale gas except that the source rock is a coal field.

Today, these three types of gas are the only ones that are industrially exploited. In addition, methane hydrates in the gas associated with water molecules are generally classified in the unconventional gas category. However, the exploitation of this last resource is set to remain at the experimental stage over the coming years.

In all cases, whether for conventional or unconventional gas, the exploited resource is always 'natural' gas, that is, mainly methane (CH_4).

Will these resources play a major role in the world energy supply?

Today, only North America has developed significant production of unconventional gas. The exploitation of this resource has allowed the United States to maintain its production close to its consumption and to avoid imports. Unconventional gas currently represents 45% of the production of gas; it may reach around 90% in 25 years. This huge growth will be due, in particular, to the production of shale gas, while the production of tight gas and coalbed methane (CBM) should remain stable over the coming years.

On a global scale, the potential for unconventional gas resources requires further study. The International Energy Agency (IEA) estimates that these resources could potentially double current gas reserves.

What are the techniques used to enable exploitation of these resources?

The main problems encountered in the exploitation of unconventional gas are linked to the low permeability of the rock. In the exploitation of conventional gas, vertical drilling is the only form of drilling necessary as the gas contained in the reservoir rises naturally due to the pressure difference. With unconventional gas, in most cases the use of vertical drilling alone would only collect a marginal quantity of gas, thereby hampering the profitability of exploitation.

A combination of technological innovations has provided solutions to these difficulties.

→ Hydraulic fracturing

The first innovation is the use of hydraulic fracturing. This technique consists of injecting large quantities of a mixture of water, sand and chemical products underground at high pressure. The mixture will create cracks in the rock, which artificially increases its permeability. However, in most cases, hydraulic fracturing on a vertical drilling is not sufficient to extract large quantities of gas.

→ Horizontal wells

The second innovation is the creation of horizontal wells, which maximises the contact surface between the gas-bearing rock and the drilling well. Usually the horizontal part of these drillings is between 1 and 2 km long. This technique is used in combination with hydraulic fracturing. Numerous fractures are made on the horizontal section of the well, thereby maximising the well's yield.

Other techniques, such as multi-well pads, which consist in creating several horizontal wells from a single drilling site, are also frequently used in the exploitation of these resources.

What are the consequences for water resources of unconventional gas exploitation?

The highest risk resides in pollution following the hydraulic fracturing operations. Indeed, potential underground leaks due to casing defects, or leaks associated with the transport of fracturing products and waste water can lead to contamination of water tables. Though there have been some cases of contamination that have resulted in convictions, these were rare cases of bad practice due to a lack of experience with these new resources on the part of the operators and the authorities. Even though greater attention must be paid to these safety issues, it seems unreasonable to cast doubt on the entire sector for these reasons.

What are the local disturbances associated with unconventional gas exploitation?

Due to the low permeability of the rocks containing these resources, unconventional gas exploitation requires drilling sites to be very close together. Even with techniques such as horizontal drilling or multi-well pads, it is necessary to make 1 to 4 drillings per km^2 over very large areas (several thousand km^2). For example, by the end of 2008, Barnett Shale in Texas had a total of 12,000 wells for the exploitation of shale gas.

The exploitation of just one site requires drilling operations to be carried out 24 hours a day for 6 to 12 months, and involves between 4,300 and 6,600 lorry trips. Though some measures can be taken to alleviate disturbances (use of less noisy equipment, construction of walls to limit the sound impact), the exploitation of these resources remains very invasive and is already encountering strong opposition in densely populated regions, such as on the north-east coast of the United States, and in Europe.

Is unconventional gas exploitation compatible with the fight against climate change?

Except for methane leaks, the CO_2 impact of unconventional gas is almost equal to that of conventional gas. However, uncertainties prevail on the existence of additional methane leaks, which could heavily impact the balance of CO_2 in unconventional gas compared to conventional gas.

In all cases, as for conventional gas, the CO_2 impact for unconventional gas is less than that of coal for electricity production. For this reason, in addition to energy efficiency measures and the development of low carbon energies, there is potential for unconventional gas to play a temporary role in the reduction of CO_2 emissions.

SUMMARY

3 I What is unconventional gas?

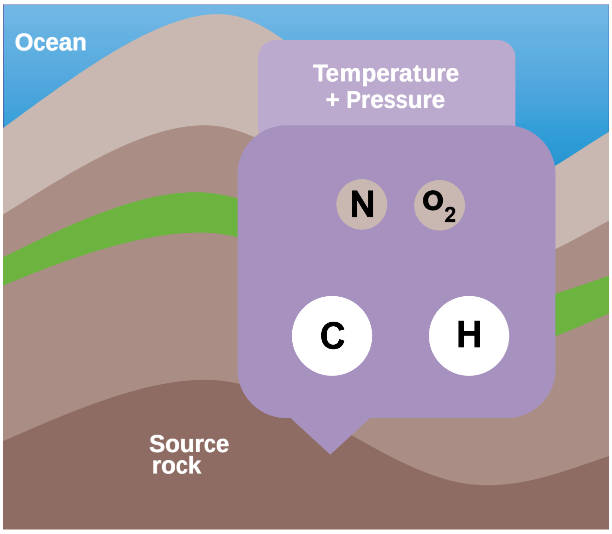
There is no precise definition for unconventional gas. This category, which encompasses a range of varied resources, is rather defined as being the opposite of conventional gas. As explained hereafter, unconventional gas differs from conventional gas by where it is found underground. However, the exploited resource is the same, since it is mainly methane (CH_4). It should be noted that some players consider that the term 'unconventional' is no longer relevant from the moment these resources are significantly exploited by the industry.

The formation of gas and oil reservoirs

Oil and gas are derived from the transformation of organic matter (algae, plankton, etc.) during a process which lasts several millions of years.

Stage 1: the deposit of organic matter

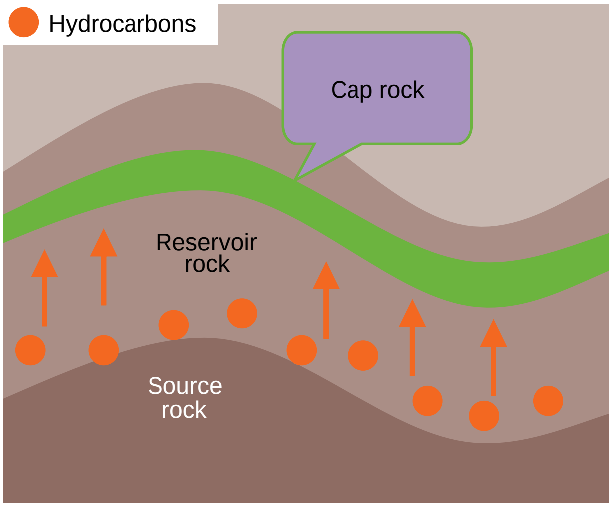
Organic matter is essentially composed of carbon (C), hydrogen (H), nitrogen (N) and oxygen (O_2). When it is destroyed by living organisms (e.g. aerobic bacteria), or becomes oxidised, the hydrogen molecules form water by combining with the oxygen (H_2O) and carbon molecules, CO_2.
However, a very small part of this organic matter (~0.1%) is deposited on the seabed where it mixes with mineral matter (clay, sand).
In this environment it is protected from oxygen and living organisms and can thus be preserved. Under certain conditions (hot climate, proximity to large river mouth conveying large quantities of vegetative waste, etc.) the proportion of organic matter can amount to 1–2%.
The mixture of mineral matter and organic matter thus forms the future source rock where the hydrocarbons will be produced.



Stage 2: sedimentation

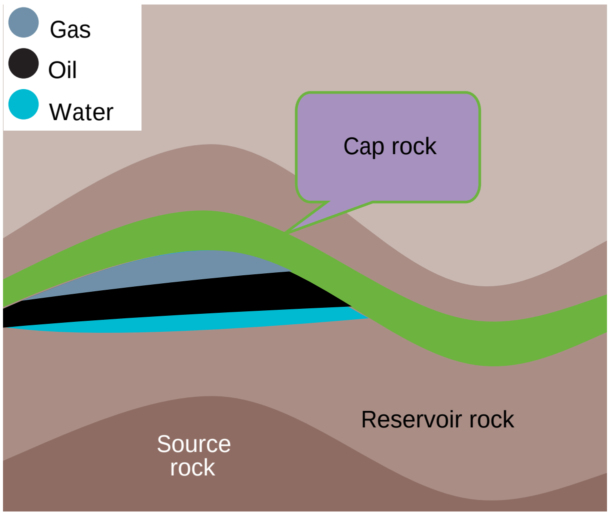
Sediments* are deposited on this source rock over several millions of years. Under the weight of successive layers, the source rock caves in from a few metres to a few hundred metres.
In doing so, the temperature and the pressure increase; between a depth of 2,000 and 5,000 metres, these increases lead to chemical reactions which transform the carbon and hydrogen molecules into kerogen and then hydrocarbons (oil and gas).

(*) Residues of variable sizes originating from the erosion of rocks or residues of organic activities (shells) or results of chemical reactions (e.g. certain carbonates).



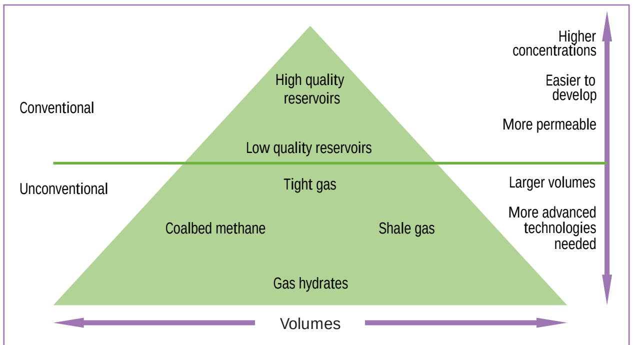
Stage 3: migration and trapping

Even though the source rock is practically impermeable, the pressure is such that the hydrocarbon molecules, which are lighter than water, rise towards the surface by moving through the interstices and porosities of the rocks that they encounter. If nothing stops them, the most volatile molecules escape into the atmosphere, while the heaviest molecules become oxidised in the form of bitumen near the surface (the largest reservoir of bitumen being the bituminous sands of Athabasca, Canada).
However, if during their migration these molecules encounter an impermeable layer (composed of salt, marl, etc.) with a geometry preventing any migration, the molecules will accumulate under this cap rock.
The porous rock containing the hydrocarbons is called a reservoir rock. It is this accumulation that constitutes the hydrocarbon fields.



Source: Natixis Asset Management / IEA, 2009.

The three main types of unconventional gas which are most intensively exploited today are shale gas, tight gas and coalbed methane (CBM).



Source: Natixis Asset Management / AIE, 2009.

Figure 1: Summary of the various types of conventional and unconventional gas

3|1 Tight gas

Tight gas is rather similar to conventional gas because it has migrated to a reservoir rock. The only difference is that the reservoir rock has a low permeability, rendering the exploitation of the reservoir more difficult. Since the differences between conventional gas and tight gas are fairly small, some countries count these resources in their conventional gas reserves. Tight gas is generally located at a depth of 1,500–3,000 m.

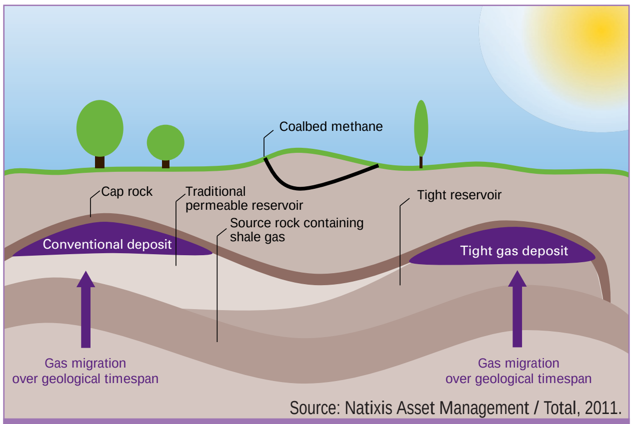
3|2 Shale gas

What distinguishes shale gas from conventional gas is that this gas has not yet migrated and is therefore still present in the source rock. Shale gas is generally located at a depth of 1,500–3,000 m.

313 Coalbed methane (CBM)

Coalbed methane (CBM)(1) is present in coal deposits. Indeed, the coal formation process implies the production of methane. The formed methane can be found in the form of a pocket, known as firedamp. It can also be absorbed by coal, in which case coalbed methane (CBM) is formed. CBM is generally produced in coal fields that are too deep, or of too poor a quality, to be exploitable. Gas can also be produced in the exploitation of coal mines in order to limit explosion risks and supply an energy source for the exploitation of the mine.

These fields are generally located at a depth of 800–1,200 m, but some formations can be found at depths of just a few hundred metres.



Source: Natixis Asset Management / Total, 2011.

Figure 2: Illustration of the geological location of unconventional gas

Shale gas, tight gas and coalbed methane (CBM) are the only types of unconventional gas currently exploited and they will continue to be developed over the coming years. For unconventional gas, this study therefore focuses on these three resources. There is also a fourth type of unconventional gas in the form of methane hydrates.

314 Gas hydrates

Gas hydrates are another form of unconventional gas resource with potentially very significant reserves (several times greater than conventional gas reserves). Gas hydrates are methane molecules derived from the decomposition of organic matter, which become 'associated' with water molecules under certain conditions (high pressure, low temperature, small quantities of methane).

In practical terms, this transformation process from methane to gas hydrates takes place under permanently frozen soils (permafrost) and in ocean sediments.

The International Energy Agency (IEA) thinks it unlikely that significant production of gas hydrates will take place over the next 25 years. Note that, if these resources were to be exploited, there is a significant risk that, in parallel with the extraction of methane, the operations might lead to unintentional emissions of methane into the atmosphere. Since methane is a gas with a global reheating potential (GHP) that is 25 times greater than CO_2, these emissions, depending on their quantity, could strongly degrade the CO_2 impact of this resource.

Finally, it should be noted that gas hydrates are a topic of concern in the study of climate change. Indeed, many climatologists have expressed the possibility of 'positive' feedback loops: the heating of the planet provokes the melting of the permafrost, which will release methane that will in turn intensify global heating. Even though these feedback loops are mentioned in the Intergovernmental Panel on Climate Change (IPCC) reports, their consequences on climate change are not quantified in IPCC scenarios.

Note that some gas resources, such as sour gas,(2) gas located in the arctic area, and deep offshore gas, are sometimes also considered as unconventional resources.

4 Reserves and production

411 Reserves(3)

Proven reserves of unconventional gas represent only 4% of total proven gas reserves (~7 trillion cubic metres (tcm) out of a total 182 tcm). Half of these proven reserves are located in the United States. However, exploration of these resources is still very recent and so far has only been conducted on basins that are already in exploitation in the United States.

---

(1) The terms Coal Seam Gas and Coal Mine Methane (CMM) are also used.

(2) Sour gas extraction requires special treatment due to high ratios of hydrogen sulfide (H_2S) and carbon dioxide (CO_2).

(3) See Appendix 1 for details of the various methods of accounting for reserves.

Units used in quantifying fossil energies

The standard units used for measuring energy are the Joule (and its derivatives: MJ, GJ, TJ) and the Wh (kWh, MWh, GWh, TWh). However, the Joule is more of an academically used unit and the Wh is a unit mainly used for electricity.

For fossil energies, the main units used are:

➜ Tonne of oil equivalent (toe)

To compare the energy consumptions of various energy sources (fossil or not), the term 'tonne of oil equivalent' (toe) is generally used.

For example, 1 toe of gas is a quantity of gas which releases the same amount of energy as a tonne of oil. Even though this unit resembles a weight unit, the tonne of oil equivalent is an energy unit, the reference to weight being used only as an analogy: 1 toe = 41.9 GJ. The following units are also used: ktoe (10^3 toe), Mtoe (10^6 toe), Gtoe (10^9 toe).

➜ Barrel

To quantify oil production, consumption or reserves, the oil barrel is generally used. The barrel is a volume unit: 1 barrel = 159 litres. However, the barrel can be converted into energy by making certain assumptions about the energy content of the oil. For instance, on average, 1 oil barrel is equivalent to ~0.14 toe. To give an order of magnitude, world oil consumption is currently between 80 and 90 million barrels per day (mb/d).

➜ bcm/tcm

To quantify gas production, consumption or reserves, billion cubic metres (bcm) or trillion cubic metres (tcm) are generally used. As for the barrel, bcm and tcm can be converted into energy by making certain assumptions on the energy content of the gas. On average, 1 bcm of gas is equivalent to ~825,000 toe.

➜ MBtu

Another frequently used unit for gas production is the British Thermal Unit:* 1 Btu ~ 1,060 J. Since this unit is very small, the units are generally expressed in thousands of Btu (MBtu) or millions of Btu (MMBtu). However, many organisations consider the acronym MBtu to mean 'millions' of Btu and not 'thousands' of Btu.** For gas prices, in particular, the price is frequently expressed in $/MBtu, systematically meaning millions of Btu and not thousands of Btu.

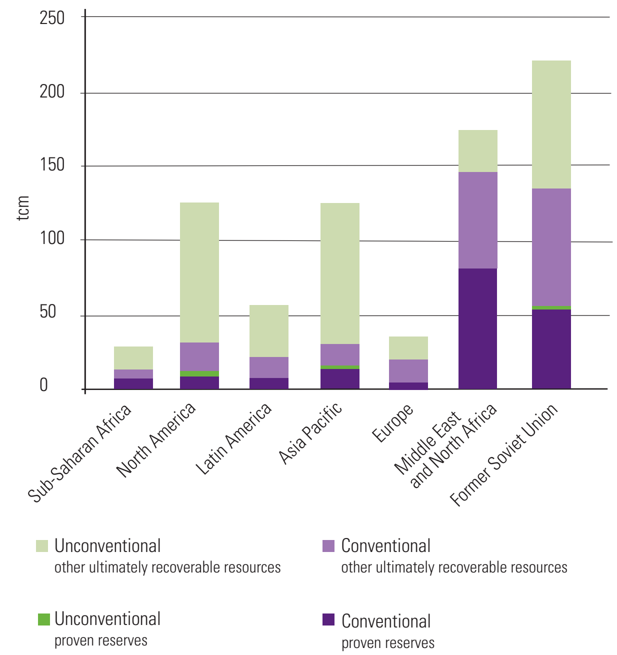
(*) This unit corresponds to the quantity of heat necessary to raise the temperature of one pound of water by one degree Fahrenheit at a constant pressure of one atmosphere.
(**) The M of MBtu originates from the Roman numbering system in which M means thousand. It can be easily confused with the M of the International System of Units (SI) which means million.

Shale gas, as we are going to see, is set to become the main production source for the United States (see Figure 4) and is present in many basins. The Barnett Shale in Texas is the historical basin where the exploitation of shale gas has been developed. This basin remains the most developed, with around 12,000 wells in 2008. Other basins are being developed, notably Haynesville (on the Texas-Louisiana border), Fayetteville (in Arkansas) and the Marcellus Shale (in the North of the United States).

Continued efforts must still be made to quantify the unconventional gas resources in the rest of the United States and even more so in the rest of the world. Once these limits are taken into account, there is no doubt that the ultimate resources of unconventional gas will be very significant. Excluding methane hydrates, the IEA estimates approximately 380 tcm of remaining ultimate resources compared to 404 tcm for conventional gas, that is, almost twice the amount of gas resources.

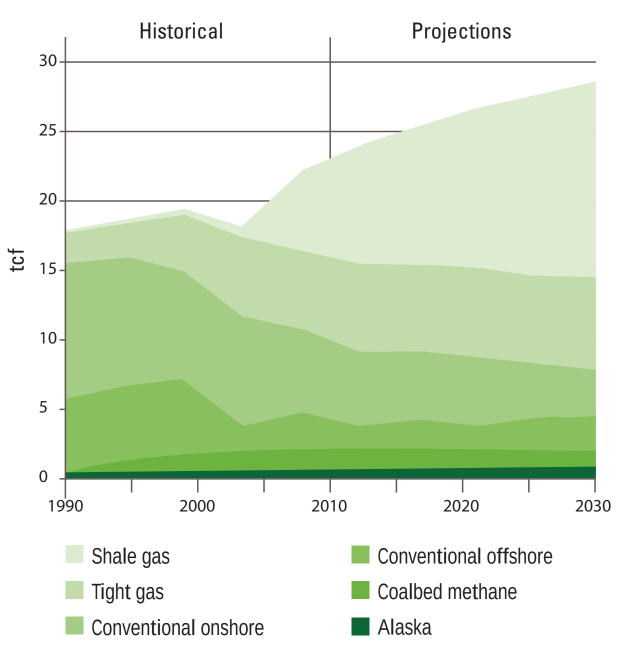
These resources also present the advantage of a geographical redistribution of resources. If these resources were to be massively exploited, areas such as North America or Asia Pacific could exhibit reserves comparable to the Middle East or Russia, which today possess the greatest share of reserves. The existence of large-scale resources in countries other than the traditional exporters presents a significant interest for consumer countries, which could then reinforce the diversification of their supply sources.

Figure 3: Geographical distribution of gas resources (conventional and unconventional gas)



Source: Natixis Asset Management / IEA, 2009.

Figure 4: Natural gas production profile for the United States



Source: Natixis Asset Management / US Energy Information Administration, 2012.

4|2 Production

Even though unconventional gas represents only 4% of proven reserves, in 2008 the production of unconventional gas accounted for 12% of world production (~400 bcm on a world production of ~3,000 bcm). This percentage is set to increase over the coming years. IEA predictions foresee a contribution of approximately 20% by 2035.

Up to now the production of unconventional gas has been almost exclusively centred in North America. **In 2008, the United States and Canada represented 90% of the world production of unconventional gas:**

- 300 bcm for the United States, that is, roughly half the national production, broken down into shale gas, tight gas and a little coalbed methane

- 60 bcm for Canada, that is, approximately one-third of national production, essentially tight gas).

In the United States in 2008, tight gas was the main source of unconventional gas production (~65% of unconventional gas production), followed by coalbed methane (~20%) and shale gas (~15%). However, according to the US DoE, even though the production of tight gas and coalbed methane should remain relatively stable over the next 25 years, shale gas should experience very strong growth, which will not only compensate for the decline in the production of conventional gas, but also increase the total production of natural gas by 25% in the US. This trend, made possible by gas price increases and new exploitation techniques (see Section 3.1), explains the increased interest in shale gas compared to other types of unconventional gas.

It should be noted that, although the emergence of coalbed methane, and shale gas in particular, is relatively recent, the production of tight gas has existed for more than 40 years in the United States.

A list of the players present in the exploitation of unconventional gas is given in Appendix 3.

5| Techniques and extraction costs

5|1 Techniques

Before going into detail about exploitation techniques for unconventional gas, it is necessary to briefly explain the extraction process for conventional gas. The principle of conventional gas extraction is relatively simple, though in reality, it requires considerable technical skill. Given that gas reservoirs are under pressure, it 'suffices' to connect the reservoir to the surface with a vertical drilling for the gas to rise naturally up the drill pipe.

The myth of the cave

A gas or oil reservoir is often represented as an underground 'cave' where hydrocarbons are likely to be located, though in reality, it's a different story. A reservoir is effectively a rock with pores which allow hydrocarbons to stay inside the rock. These pores can sometimes be interconnected.

Therefore, two parameters are generally used to characterise a reservoir:

- **Porosity**, measured as a percentage which represents the volume of voids and pores in the rock.
- **Permeability**, measured in Darcy (milliDarcy: mD, microDarcy) which represents the level of interconnection of the pores and therefore, the aptitude of a fluid, liquid or gas to circulate in the rock.

This aptitude also depends on the fluid's viscosity (the lower the viscosity, the easier it is for the fluid to circulate in the rock).

Even though a high porosity indicates a strong capacity for hydrocarbons in a rock, this does not mean that it will be easy to exploit the resource. Some rocks, such as volcanic pumice stones, have good porosity, but the pores are isolated from one another which prevents any circulation of liquids.

NB: In the same way, this representation in the form of an underground cave, or an underground river, is common for aquifers; it is also just as erroneous. Like hydrocarbon reservoir rocks, aquifers are underground rocks that are sufficiently porous and permeable to allow the circulation of water.

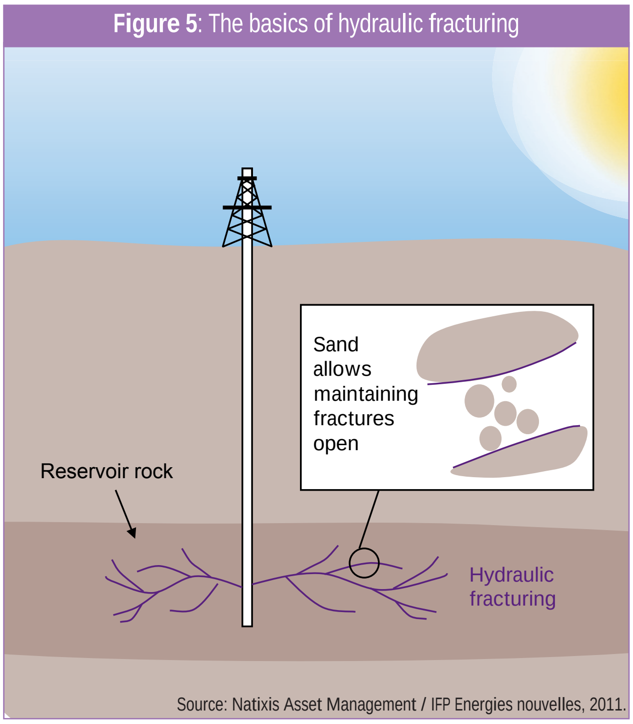
Tight gas[4] and shale gas are found in rocks with low permeability. This is also often the case for coalbed methane. Therefore, a traditional vertical well would extract only a very small quantity of gas since there is poor circulation of fluid inside the rock. It was necessary to turn to other techniques to exploit these resources.

Hydraulic fracturing

To make gas exploitation profitable in low permeability rocks, it is necessary to artificially create the rock's permeability. The technique used, called hydraulic fracturing, consists of injecting a mixture of water (~95%), sand (~5%) and chemical products (<0.2%) into the deposit at high pressure and in large quantities. The pressurised water fractures the rock, and the sand keeps the fractures open to allow the gas to circulate. The chemical products are used to facilitate the operation: biocides limit the growth of bacteria in the drill pipe, hydrochloric acid dissolves any rock debris in the pipe, special products reduce losses through friction and keep the sand suspended in the water.

It should be noted that hydraulic fracturing is not a new technology. It was commercially introduced by the American company, Halliburton, at the end of the 1940s. Halliburton asserts that since the 1940s more than one million hydraulic fracturings have been made, enabling the extraction of ~17 tcm (a total of 90 tcm of gas has been consumed since the beginning of gas exploitation).

Figure 5: The basics of hydraulic fracturing



Source: Natixis Asset Management / IFP Energies nouvelles, 2011.

The recourse to fracturing is standard in the exploitation of shale gas and tight gas, and is frequently used for the exploitation of coalbed methane. This technology is also used to improve the recovery ratio of traditional fields, just as much for gas as for oil.

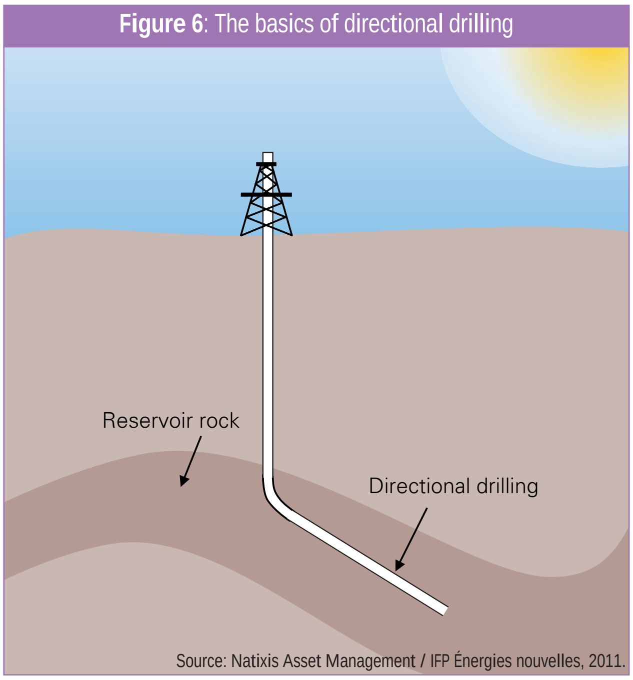
---

(4) Initially, tight gas corresponded to gas present in reservoirs with a permeability of less than 0.1 mD in the United States. Today, tight gas is more present in reservoir rocks (like conventional gas), though it is not possible to exploit the field with traditional extraction techniques.

Horizontal or directional drilling

Directional drilling is another technique which has helped to significantly improve the recovery ratio for reservoirs with low permeability. Hydrocarbon reservoirs can have very variable geometries. Directional drilling orients the direction of the drilling to maximise the surface contact between the drilling well and the reservoir, thus improving the recovery ratio.[5]

Figure 6: The basics of directional drilling

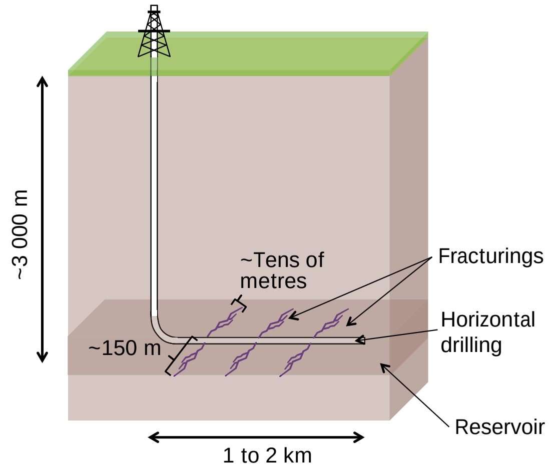


Source: Natixis Asset Management / IFP Énergies nouvelles, 2011.

Conventional wells could already be inclined a few degrees in relation to the vertical. Directional drilling makes it possible to drill so that the deep-down section is horizontal in relation to the vertical section. In general, the horizontal part measures around 1,000–2,000m, though longer distances are indeed possible (the record exceeds a length of 10,000 m).

This technique, which was first experimented with in 1929 in Texas, only became developed commercially in the 1980s within the framework of the exploitation of conventional fields.

It is now possible to combine the horizontal drilling and hydraulic fracturing techniques. This combination makes it possible to multiply the hydraulic fracturings along the entire horizontal section of the drilling (30 fracturings on average for a horizontal section of 1,000 m) therefore greatly improving the recovery ratio. Figure 7 shows the combined use of both techniques.



Source: Natixis Asset Management / Total, 2011.

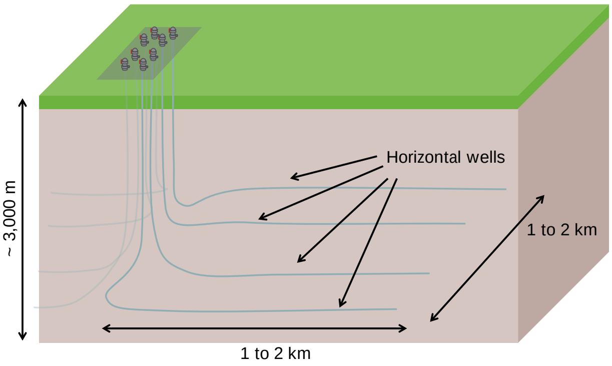
Figure 7: Combined use of hydraulic fracturing and horizontal drilling techniques

This combination of hydraulic fracturing and horizontal drilling first took off during the 2000s at the Barnett Shale site in Texas. Such a technique enabled the profitable exploitation of shale gas and has almost become standard in shale gas exploitation, and more and more frequent in tight gas exploitation. It is also sometimes used in coalbed methane exploitation.

Multi-well pads

Today, to optimise a drilling site it is possible to carry out several directional drillings on one single site. This technique, called multi-well pads, increases the quantity of gas extracted on a single site; it also reduces costs and the number of exploitation sites needed.

This technique can be used to make approximately 20–30 drillings from one single site, and multi-well pads are generally made up of six to eight wells.



Source: Natixis Asset Management / Total, 2011.

Figure 8: Example of a multi-well pad

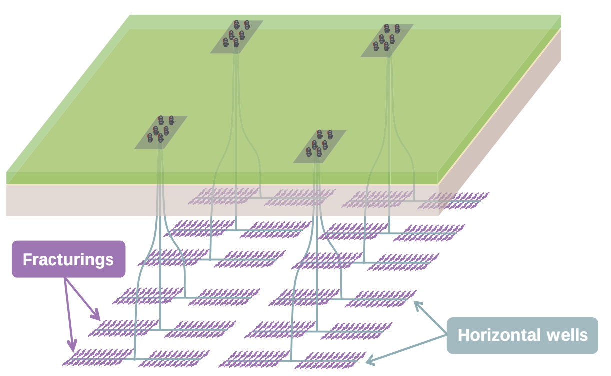
This multi-well pad technique is also used in combination with hydraulic fracturing and horizontal drilling. The combination of these three techniques optimises yields (see Figure 9).

---

(5) Conventional fields located under areas that are difficult to access can also be reached with directional drilling. For example, by using this technique, onshore drilling can be used to reach areas where, with a traditional vertical drilling technique, it would have been necessary to carry out offshore drilling.

Since unconventional gas resources are normally very spread out, these installations have to be repeated many times. Thus, to exploit a field, it is necessary to install 1–4 production sites per km^2. Since fields extend over tens of thousands of km^2, the impact on the land use can potentially be very significant (see Section 4).

Figure 9: Coverage of a given area using all three techniques



Source: Natixis Asset Management / Chesapeake / Statoil, 2008.

Specific features of gas exploitation

As already mentioned, the strong growth of shale gas production in the United States was only possible due to the combination of these techniques and, in particular, the significant use of hydraulic fracturing. For example, at the Marcellus Shale site in the United States, industrialists estimate that 90% of the wells will be made using the three techniques combined.

Tight gas uses more or less the same exploitation techniques as shale gas. The only difference is due to the fact that, depending on the reservoirs, the permeability of the rock may be better and therefore may not necessarily require horizontal drillings. However, these techniques, which improve the yield of the wells, are being used more and more.

As for coalbed methane, directional drilling with hydraulic fracturing is less frequently used, even though this technique is being more widely employed.

It should be noted that, for coalbed methane, once the drilling is complete, and before gas production begins, it is often necessary to pump out large quantities of water which is naturally present in the coal fields. The state of the water can be clean or slightly polluted, or it may even require special treatment, though each case is different.

512 Production stages[6]

More specifically, exploitation of unconventional gas resources using the aforementioned techniques takes place in several stages.

- **Preparation of the pad**

The first stage consists of levelling a pad of approximately two hectares to accommodate the various items of equipment needed for the exploitation of the field. A road also has to be built to access this pad.

This stage lasts approximately one month. Earth moving equipment (bulldozers, diggers, etc.) is used to perform the operations.

- **Drilling**

The vertical part of the drilling is similar to a traditional gas or oil drilling (several steel pipes filled in with cement to isolate the drilling of the surface area covered). The horizontal part is carried out with specific tools.

This drilling stage lasts approximately 1–2 months to make a single horizontal well, and 6–12 months for a standard installation with six multi-well pads. On the surface, this stage is characterised by the presence of a derrick to do the drilling.

- **Reservoir fracturing**

Once the drilling is complete, the reservoir fracturing stage can begin. First of all, the horizontal section of the drill pipe is perforated at several points to allow the circulation of fluids between the pipe and the reservoir. Once the pipe is perforated, a mixture of water, sand and chemical products is pumped at high pressure into the drilling to create micro-cracks in the rock. 10,000–30,000 m^3 of water is then pumped underground. A highly variable amount of water rises to the surface (between 15% and 80%). The recovered water is stored in containers or water storage pits. It can also be reused for other fracturings (to create other wells for multi-well pads) or sent to a sewage treatment station.

This reservoir fracturing operation, including all the water treatment operations, also lasts 1–2 months for a single horizontal well, and therefore 6–12 months for six wells. On the surface, the derrick is replaced by a fleet of lorries to pump the mixture into the drilling.

- **Cleaning and testing the site**

Once the fracturing operations are complete, the site must be cleaned, e.g. transporting the waste away for treatment and excavating the retention tank. The drilling must also be tested before production can begin.

These operations last 1–2 months for one single production site. On the surface, earth moving equipment is necessary, as well as lorries to transport the waste.

- **Production**

Once all of these pre-production operations are complete, the only thing left to do on the site is place the 'frac tree' or 'christmas tree' on the wellhead and install the tanks to store the extracted resource.

The well then produces natural gas for 10–15 years. Note that it can happen that, after a given time, the well is refractured to increase its production capacity.

---

(6) See the Chesapeake Company website for videos illustrating the various production stages of a shale gas field: http://www.chk.com/Media/Educational-Library/Animations/Pages/default.aspx.

As explained in the previous section, the exploitation of coalbed methane often requires an additional pumping stage to pump out the large quantities of water that are naturally present in the coal fields.

Table 1 summarises the duration of a standard shale gas site exploitation.

Table 1: Estimation of the duration of a standard shale gas site exploitation
(multi-well pad, 6 horizontal drillings with hydraulic fracturing)

Pre-production	**Production**
(intensive activity on the exploitation site)	(reduced activity on the site)
1–4 years	10–15 years

Source: Tyndall Centre, 2011.

513 Costs

The IEA provides an estimation of the production costs of unconventional gas compared to other types of gas.

Figure 10 shows that the production costs of unconventional gas, i.e. tight gas, shale gas and coalbed methane (CBM), are between $2.70/MBtu and $9/MBtu.

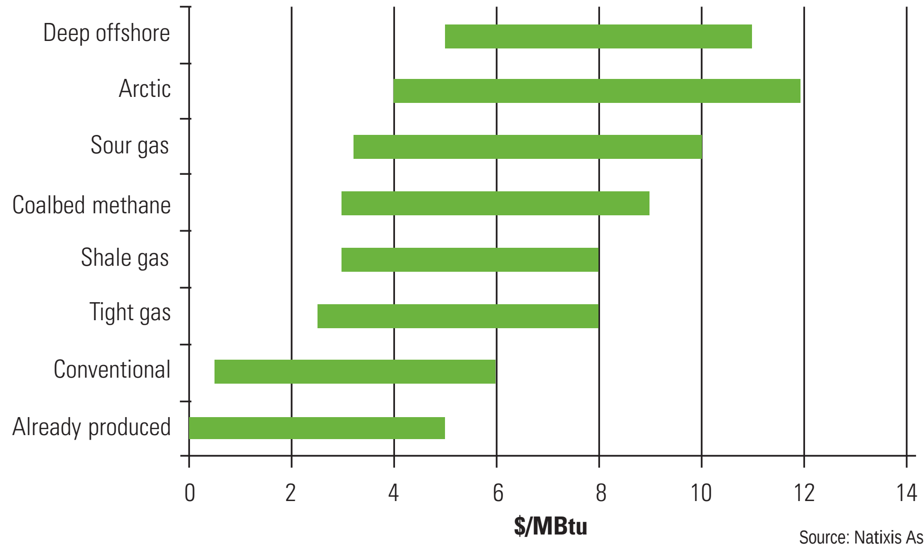
These costs are to be compared with:

- gas that has already been produced with a production cost below $5/MBtu
- conventional gas with costs between $0.5/MBtu and $6/MBtu
- sour gas between $3.10/MBtu and $10/MBtu.

Transport costs also have to be added to these production costs. The transport can be carried out by pipeline or by conversion units converting the gas into liquefied natural gas (LNG) for shipment by boat. The IEA estimates the transport cost by pipeline to be between $0.30/MBtu and $1.20/MBtu for 1,000 km and between $3.10/MBtu and $4.70/MBtu for transport by LNG.

Taking into account these various parameters, the IEA estimates, for example, that the shale basins currently exploited are profitable for a gas price (excluding transport) of between $3/MBtu and $6/MBtu.

Figure 11 shows that the production of gas from unconventional gas resources leads to increased production costs. However, this does not mean that one can conclude that the exploitation of unconventional gas leads to a rise in the price of gas.



Source: Natixis Asset Management / IEA, 2009.

Figure 10: Production costs of various types of gas

Gas prices

Unlike oil, gas is difficult to transport and requires the construction of heavy infrastructure (pipelines, LNG terminals) for its transport. There are consequently major gas price differences between various consumption areas.

Three main consumption areas are generally distinguished:

➜ Europe

Western Europe, which has extremely limited gas resources, relies heavily on imports by pipeline from Russia, Norway and Algeria.

➜ Japan

Japan and South Korea are historically the major gas consumers of the Asian region. Neither of these countries has gas resources, and both are isolated from major production sites. They had to set up infrastructure to import massive amounts of LNG from Malaysia, Australia, Indonesia, the Middle East, Russia and other countries, justifying the higher purchase prices for this area.

In both of these areas, prices are generally fixed by long-term contracts indexed on the price of oil.

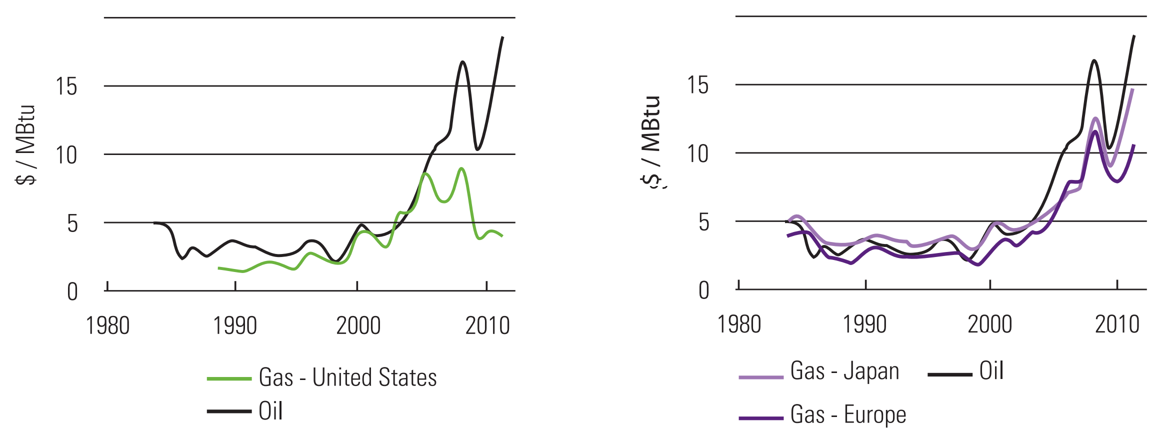
➜ United States

The United States historically produced enough conventional gas to satisfy its needs. However, in the 1980s, production was no longer sufficient to face growing demand, despite the fact that US production covered between 80% and 90% of demand.

During the 2000s, the production drop in conventional gas should have led to a considerable increase in LNG imports and therefore a price increase in the area. However, the unexpected boom in unconventional gas in the United States disrupted these forecasts.

As explained, the price of gas is completely uncorrelated with production costs and is generally indexed via long-term contracts based on the price of oil. The boom in unconventional gas enabled the United States to reduce its use of imports and to avoid having to match its gas prices to those in Japan.

Figure 11: Evolution of the price of gas in relation to the price of oil (1984–2011)

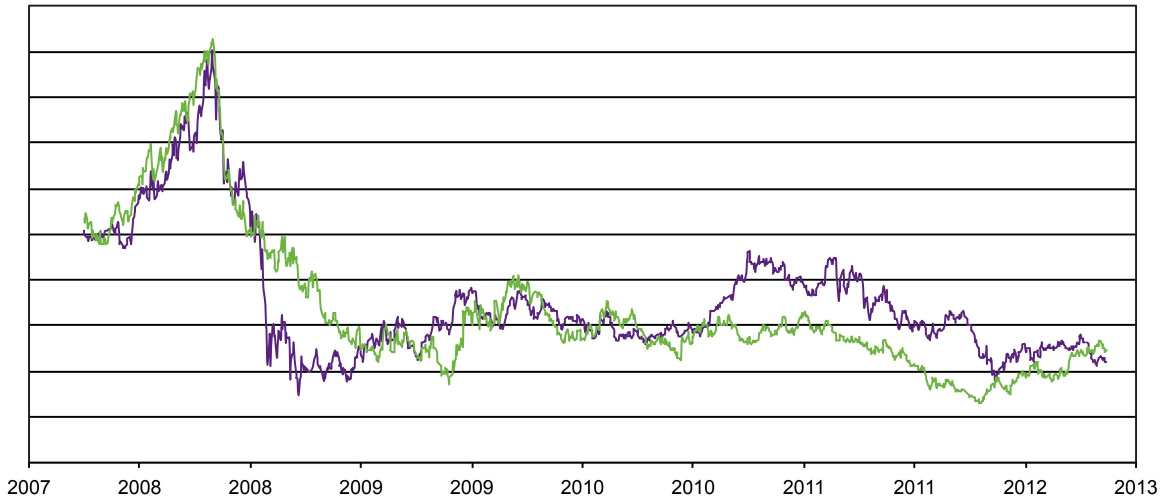


Notice on these charts that since 2005, the year when unconventional gas experienced strong growth in North America, the price of gas in the United States was dramatically uncorrelated with the price of oil, contrary to Japan and Europe, where gas prices evolved similarly to the price of oil.

Source: Natixis Asset Management / BP, 2012.

This lack of correlation between the price of gas and oil due to the exploitation of unconventional gas and the issue of energy independence explains the continued interest in shale gas on the part of many political bodies. The paradox is that the drop in the price of gas was so great that it degraded the profitability of these exploitations, and consequently adversely affected the profitability of the companies that had invested in these resources. The graph in Figure 12 shows the strong correlation between the price of gas and Chesapeake's share price; Chesapeake is one of the main operators of shale gas in the United States.

Figure 12: Evolution of the price of natural gas in the United States compared with the value of the Chesapeake company's shares



In green: the evolution of the price of gas in the United States.
In purple: the stock market evolution of the shares of Chesapeake, one of the main shale gas operators in the United States.

Source: Bloomberg.

6 | Main environmental and social impacts

6|1 Climate change

There is a current debate surrounding the impact of unconventional gas on climate change.

There are two types of issue here:

- ➜ increasing the size of gas reserves would not be compatible with the fight against climate change
- ➜ the CO_2 footprint of unconventional gas would be greater than the footprint of conventional gas.

Would increasing the size of gas reserves be compatible with the fight against climate change?

Some players consider that current conventional gas reserves are already sufficient to exceed the CO_2 emission objectives and that, as a result, the use of additional unconventional resources would not be compatible with the fight against climate change.[7]

For gas on a global scale, it is certain that conventional resources would be sufficient to cope with demand in the next 20 years. Nevertheless, there are huge imbalances between the countries possessing gas reserves and the countries consuming them.

Thus, if the United States had not had access to unconventional gas, the drop in conventional gas production could have been compensated for in a number of ways:

- ➜ Importing liquefied gas with a CO_2 footprint greater than that of the gas produced on site (due to additional transformation and transport operations).
- ➜ Increasing recourse to coal the reserves of which are abundant in the United States, but where the CO_2 footprint is greater than that of gas.
- ➜ Significantly improving energy efficiency and/or increasing renewable energy production.
  Although this option would have been the most favourable in terms of the climate, it would have required major efforts which do not correspond to the policies currently in place in the United States. In addition, even if such efforts were deployed with a view to fighting climate change, they would, above all, have to limit the recourse to coal (more CO_2 intensive) and not the recourse to gas.

It is, therefore, not so easy to conclude that the US's choice to exploit unconventional gas has a negative impact on climate change.

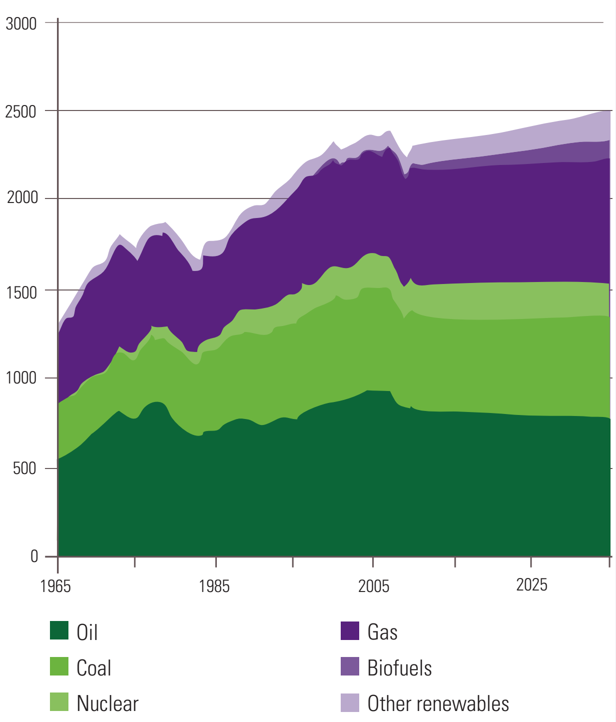
Note that, between 2005 and 2010, the CO_2 energy emissions of the United States dropped by 7%. The International Energy Agency attributes this drop not only to an improvement of the energy efficiency in transports, but also to a 'major transfer' from coal to gas in the production of electricity.[8]

---

[7] *On this subject, see in particular the study published in Nature magazine: Greenhouse gas emission targets for limiting global warming to 2°C, 2009 (10.1038/nature08017), Meinshausen, M., Meinshausen, N., Hare, W., Raper, S. C. B., Frieler, K., Knutti, R., Frame, D. J. & Allen, M.*

[8] *Financial Times, 23 May, 2012, 'Shale gas boom helps slash US emissions (http://www.ft.com/intl/cms/s/0/3aa19200-a4eb-11e1-b421-00144feabdc0.html#axzz2AOgv1BI1).*

Figure 13: History and predictions of energy consumption in the United States

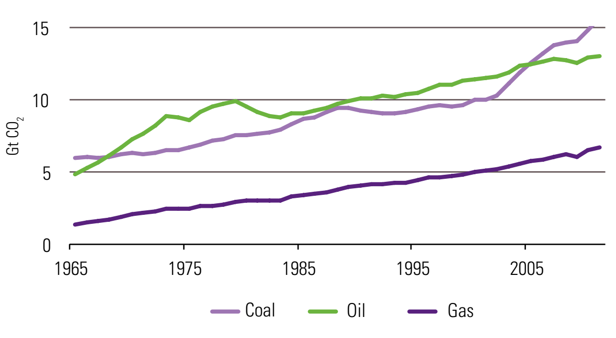


Source: Natixis Asset Management according to BP, 2012 for the data 1965–2011 and US Energy Information Administration, 2012 for the growth rates 2011–2035.

Similarly, if China were to succeed in reducing its coal consumption by exploiting unconventional gas present in its subsoil, there would be a significant reduction of the country's CO_2 output.

We can see from these two examples that, even if energy savings and renewable energies report much more favourable CO_2 footprints, the recourse to unconventional gas is not *a priori* necessarily incompatible with the CO_2 emission reduction strategies, particularly in countries which rely heavily on coal.

The urgency to limit the recourse to coal is now stronger than ever after the greatest growth experienced by this energy over the last 10 years. Since the mid-2000s, coal has thus become the main source of greenhouse gas emissions ahead of oil.



Source: Natixis Asset Management / IEA, 2011.

Figure 14: Estimation of greenhouse gas emissions per fuel (1971–2009)

However, it is still difficult to determine whether the discovery of new gas reserves will contribute to increasing the use of fossil energies or will limit the use of coal. The table below lists the main arguments for each of the approaches.

Table 2: Summary of the main arguments for and against the use of new gas resources

For	Against
• The carbon footprint of gas is half the size of that of coal for the production of electricity. • Coal is a low-cost fuel with a significant amount of reserves. A reduction of gas consumption would automatically lead to an increased use of coal.	• Even though gas has a better carbon footprint compared to other fossil energies, it remains a major source of greenhouse gas emissions. • The discovery of new resources contributes to reducing the price of fossil energies which will delay the development of renewable energies and the implementation of energy efficiency measures.

Given the arguments in Table 2, it is clear that a simple calculation will not provide the answer to the question, 'Is increasing the size of the gas reserves compatible with the fight against climate change?'.

Would the CO_2 footprint of unconventional gas be higher than that of conventional gas?

As explained in Section 3, the extraction techniques for unconventional gas are significantly different from those used for conventional gas.

For **shale gas**, the Tyndall Centre, an English climate change research centre, published a report on additional sources of emissions linked to the extraction of this resource. The report concludes that the additional emissions in the life cycle approach are between 0% and 3%. These additional emissions are due to a great extent to the hydraulic fracturing processes. The other significant sources of emissions in order of importance are: horizontal drilling, transport of water and waste water, and treatment of waste water.

Since extraction techniques are more or less the same for **tight gas** and **coalbed methane**, it is estimated that the additional emissions associated with the extraction of these types of gas are in the same order of magnitude as for shale gas.

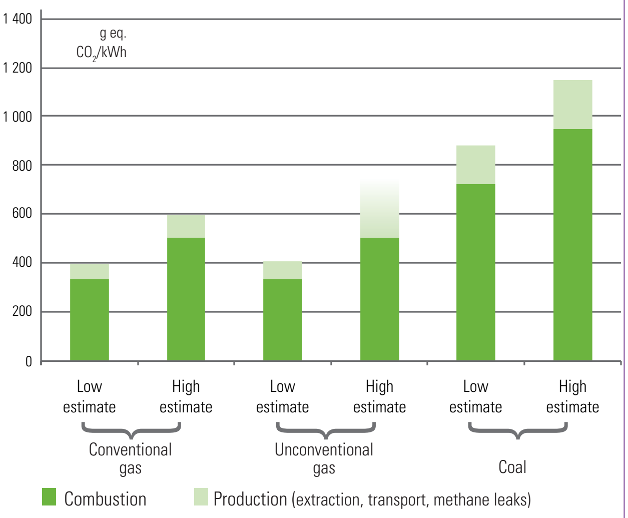
However, the Tyndall Report does not take into account possible additional gas leaks during the extraction process. As a reminder, extracted natural gas is composed almost exclusively of methane.
Since methane has a global heating potential 25 times greater than that of CO_2, the slightest additional leak will have very significant consequences on the gas's carbon footprint.
For example, the French Environmental and Energy Control Agency (ADEME) estimates that additional leaks amounting to 1% will raise the gas's global impact by 10%. This question is therefore very sensitive.

However, no study to date has quantified these leaks on a representative well sample. Only a study conducted by Cornell University researchers (Howarth R. W., 2011) has tried to quantify them.

Even though this study encountered much criticism (see Appendix 2), it is worth noting that it considers that additional methane leaks linked to the exploitation of shale gas vs. conventional gas are around 2%, which, in the life cycle approach, leads to an estimated 20% increase in CO_2 emissions from the exploitation of shale gas compared to conventional gas.

By taking into account these various elements, the bar graph below shows, for the production of electricity,[9] the greenhouse gas emissions in the life cycle approach associated with the production of one electric kWh for each fuel type. Note that in all cases gas remains a higher performing fuel than coal in terms of CO_2 emissions (see Appendix 2 for more details on the assumptions made).[10]

Figure 15: Estimation of greenhouse gas emissions for the production of electricity (conventional gas, unconventional gas and coal)



- For gas, the high bar sections correspond to power plants with an efficiency of 40%, corresponding with a low estimation of the efficiency of the power plants installed base throughout the world; the low bar sections correspond to an efficiency of 60%, corresponding with the highest performing gas power plants.
- For coal, the high bar sections correspond to power plants with an efficiency of 36%, corresponding with an estimation of the power plants installed base throughout the world; the low bar sections correspond to an efficiency of 47% corresponding with the highest performing coal power plants. The lighter green section of the high estimation of unconventional gas corresponds to the uncertainty of the existence of additional methane leaks.

Source: Natixis AM estimations based on ADEME.

However, other means of producing electricity, particularly renewable energies or nuclear, have significantly lowered CO_2 emissions for the production of electricity based on gas.

Table 3: CO_2 emissions per energy source (life cycle analysis)

Energy sources	Technology	Greenhouse gas emissions (g eq. CO_2/kWh)
Natural gas	Open circuit gas turbine	440
	Combined circuit gas turbine	400
Solar	Photovoltaic	100
Biomass	Biomass plant	30
Wind	Onshore	30
	Offshore	10
Nuclear	Light water reactor	15
Hydroelectricity	Large	20
	Small	5

Source: European Commission, 2007.

Even though there are energies emitting less CO_2 than unconventional gas, we estimate that the exploitation of unconventional gas can be compatible with the fight against climate change. The relevance of employing these resources must be evaluated vs. local contexts. In each case, it is necessary to try to understand, in particular, whether or not these new resources can replace other, more polluting, resources.

612 Water management

Beyond the climate aspects, unconventional gas is highly controversial in terms of water, particularly because of the fears of contamination of water tables and significant water consumption.

Water table pollution risk

The pollutants

During drillling operations and unconventional gas exploitation, operators must ensure that there is no possible connection between drilling and water tables.

Indeed, various pollutants can affect the integrity of the water tables:

- Drilling sludge

Just as with traditional drilling, drilling fluid has to be used to control the pressure in the drilling and evacuate the drilled rock debris. This fluid is usually composed of oil or water, salts or other particles which improve the sludge density, as well as various chemical products. This fluid is generally toxic.

- Fracturing fluids

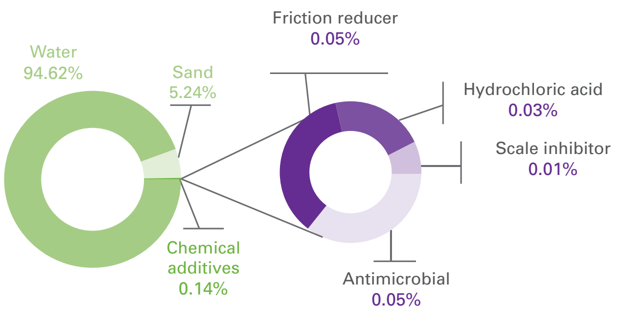
As already mentioned, during hydraulic fracturing, a mixture of water (~95%), sand (~5%) and chemical products (<0.2%) is injected to fracture the rock, to prevent the fractures from closing and to allow the gas to flow into the well. The purpose of the added chemical products is to improve the efficiency of the fracturing and hence the well's profitability.

---

(9) The production of electricity is the use which makes the most sense in comparison with gas and coal. Both of these energies are heavily used throughout the world for the flexible production of electricity.

(10) Using different assumptions, a study dedicated to this question of the gas's carbon balance sheet conducted by Deutsche Bank and the Worldwatch Institute comes to the same conclusions on the natural gas/coal comparison: DB/Worldwatch Institute, 2011, Comparing Life-Cycle Greenhouse Gas Emissions from Natural Gas and Coal, http://www.worldwatch.org/system/files/pdf/Natural_Gas_LCA_Update_082511.pdf.

Figure 16: Composition of chemical products used in hydraulic fracturing



Antimicrobials *prevent the occurrence of bacteria in the reservoir, which would otherwise lower the yields. This type of product is used notably for water treatment, as a disinfectant, or for medical sterilisation relating to anti-microbial agents.*
Scale inhibitor *allows a homogeneous distribution of the sand in the fluid. This type of product is used notably for water treatment, and is found in household cleaning products or de-icing agents.*
Hydrochloric acid *dissolves some rock types in order to improve the reservoir's permeability. This type of product is used notably in swimming pools or household cleaning products.*
Friction reducer *makes it possible to reduce the power used to inject the fluid. This type of product is used notably for soil and water treatment, or as an absorbant in 'babies' nappies.*

Source: Natixis Asset Management / IFP Énergies nouvelles, 2011.

In the United States, the composition of these chemical products has for a long time been protected by industrial trade secret rights, leading to many questions from the population. Since 2010, pressed particularly by the US Environmental Protection Agency (EPA), voluntary publication of the chemical products used has become the norm for manufacturers. With this information, we now know that the fluids contain dangerous or carcinogenic substances, even when present in small quantities. The industry is currently searching for alternative solutions to reduce the dangerous nature of these products.

- Natural elements

Clay characteristically retains organic matter, heavy minerals and radioactive elements. But hydraulic fracturing disturbs the formation and so when water is forced to circulate in these formations, it can rise, loaded with toxic substances, and pollute water tables.

Table 4: Example of 'natural' pollutants appearing in natural deposits

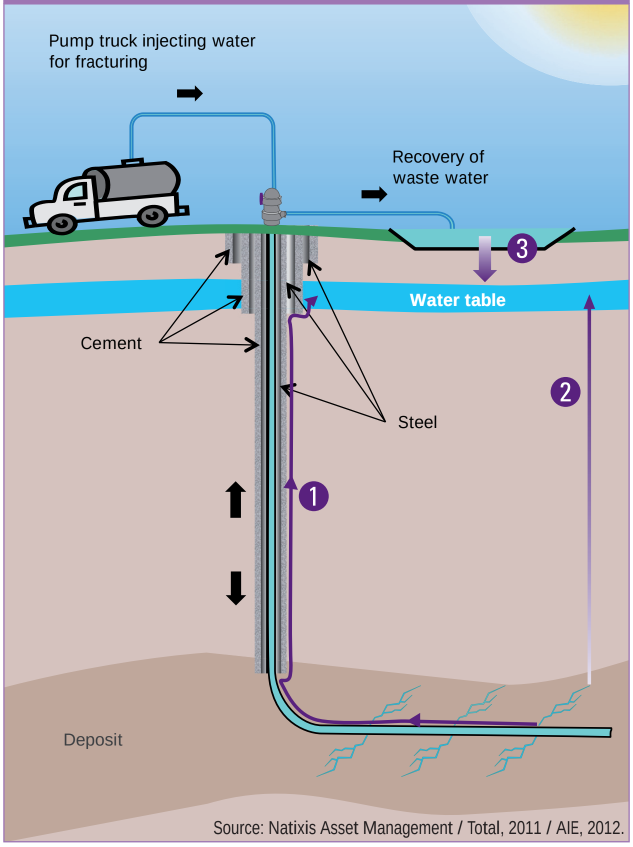
Pollutants	Examples
Fluids coming from the formation	Brine
Gas	Natural gas (methane, ethane), CO_2, nitrogen, helium, hydrogen sulphide
Traces	Mercury, lead, arsenic
Radioactive elements	Radium, thorium, uranium
Organic matter	Organic acids, polycyclic aromatic hydrocarbons (PAHs), volatile organic compounds (VOCs)

Source: EPA, 2011.

Possible connections between drillings and water tables

Since the fracturing fluid contains both chemical products and natural elements that are dangerous for human health, it is absolutely necessary to prevent it from coming in contact with water tables used as a source of drinking water.

Figure 17: Main water table contamination risks



Source: Natixis Asset Management / Total, 2011 / AIE, 2012.

Contamination risks fall into three categories:

- Improper sealing ①

Oil and gas drillings, both conventional and unconventional, pass through the water tables which are usually located several hundred metres below the surface. To isolate the drilling from the water tables, operators install several steel pipes (casings) surrounded by special cement. The pipes must be 'cemented' with great care. Beside preventing the fluids circulating inside the drilling from coming into contact with the water table, it is important to make sure that fluids do not rise 'behind' the steel casing. If this cementing is not performed correctly, there is a risk that some of the injected fluid may rise through the hole made for the drilling, but outside the casing, and contaminate the water table.

The quality of the casing is important, even for traditional drilling, to prevent the drilling fluid from contaminating the water tables. Hydraulic fracturing makes this stage even more crucial. This technique requires much larger water volumes and much higher pressures than those for traditional drillings, which consequently increases the risks of deterioration of the steel and cement barriers.

For existing wells, some cases of imperfect sealing of the cement column have already led to water table contamination problems. For instance, in May 2011, the Chesapeake company was ordered to pay a fine of $900,000 for contaminating water in Bradford county. Nevertheless, these are isolated cases showing bad practice due to a lack of experience with these new resources on the part of operators and of the authorities. Even though greater attention must be paid to safety issues, it seems inappropriate to question the entire sector for these reasons.

- **Connection between the fracture area and water tables** ②
  For the deepest drillings, it seems highly unlikely that fracturing the rock will generate fractures up to water tables located at a depth of a few hundred metres, since the fracturing takes place at a depth of 1,000–3,000 m and the fractures do not theoretically exceed one hundred metres. Some scientists stress the risk that hydraulic fracturing can intensify existing natural fractures and so create potential paths toward the surface.[11] Up to now, no proven case of pollution of this type has been reported.

- **Poor surface water management** ③
  Two surface water management issues can lead to contamination of the water tables:
  - *handling and routing of waste water on the surface.* The routing of residual water to water treatment units generates risks of accidental spills – all the more possible if the water treatment units are not located close to the sites.
  - *water storage pit leaks.* As already mentioned, waste water loaded with suspended particles passes through storage pits on site. The waterproofing of these pits is generally ensured by a plastic covering. There is a risk of defective waterproofing of the basins.

In both cases, these risks are highly comparable to other industrial activities. This point must be watched by the regulator, but is not relevant enough to bring the entire sector into question.

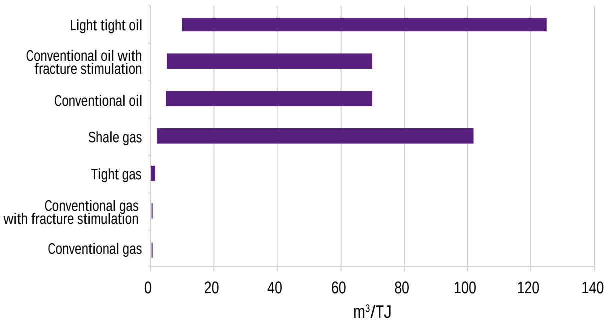
The US EPA is currently working on a new study on the impact of the exploitation of shale gas on underground water.[12] This study should provide new elements for the evaluation of these risks.

Water consumption

Shale gas and tight gas

The volume of water required for a drilling and its hydraulic fracturing varies according to the geology of the exploitation areas and the depth of the well, but is usually between 10,000 and 30,000 m³. As shown in Figure 18, between the uncertainties on well yields and the differences of water quantities to be used depending on the geology, there is a wide range of water consumption for the production of hydrocarbons.

Figure 18: Estimation of water consumption per energy type



Note: for oils, the figures include 5–15 m^3/TJ necessary for refining. Also for oils, the high sections correspond to operations of assisted recovery where water is injected in the drilling to increase the pressure in the reservoir and increase yields.

Source: Natixis Asset Management / AIE, 2012.

However, despite these large variations from one field to another, it can be concluded that hydraulic fracturing demands larger water volumes than traditional hydrocarbon exploitation. In arid areas, this can create local competition issues with other uses such as agriculture, other industrial activities or local community consumption. Even though this water consumption can effectively lead to issues in some regions, it does remain well below the water consumption for agriculture.[13]

To reduce this consumption, manufacturers are trying to increase the recycling of fracturing water. Once the fracturing is completed, some of the water rises to the surface. The flowback water is between 15% and 80% of the injected water, depending on geological conditions. After treatment, most of the water can be used again for hydraulic fracturing.

This issue of water consumption must, therefore, be locally analysed according to the availability of water resources. Operator actions consisting of establishing a dialogue with local communities and setting up the best techniques available are expected to limit water needs. In areas under water stress, the project's viability is questionable from both an economic and a societal point of view.

Characteristics of coalbed methane

One characteristic of coalbed methane is that it is located in reservoirs containing large quantities of water. Since this water must be extracted before the field can be exploited, the result is that, even with fracturing operations, coalbed methane fields are generally water producers rather than water consumers. However, the extracted water requires special treatment.

Hydraulic fracturing techniques pose new contamination risks for water resources. Contamination cases due to poor fracturing quality have already led to convictions for some operators. However, the technical challenges to be met are comparable to other industrial activities. Even though this point calls for greater attention on the part of regulators to supervise operator practices, it should not bring the entire sector into question.

---

(11) See notably Warner and al., 2012, Geochemical evidence for possible natural migration of Marcellus Formation brine to shallow aquifers in Pennsylvania – summary available at: http://www.pnas.org/content/109/30/11961.

(12) See http://www.epa.gov/hfstudy/.

(13) Agriculture represents ~70% of global water consumption.

6|3 Land use and local disturbance

Land use

The area occupied by an unconventional gas exploitation site is relatively limited.

- During the drilling and fracturing phases, the area used is between one and two hectares (that is, a square of 100–150 m per side).
- In the production phase, the used surface is no more than 0.4 to 1.2 hectares. Access roads and corridors must be added to this surface to allow water, gas and electricity to circulate.

However, even though an exploitation site occupies only a relatively small surface, placing a field of shale or tight gas in production requires creating between 1 and 4 exploitation sites per km^2 over very large surfaces (several thousand km^2). These figures take into account the creation of horizontal multi-well pads to reduce soil occupancy; a technique which is becoming the norm. The impact would be even more significant if these techniques were not used.

The local impact of deposits that are close together can have a significant effect on the bird's-eye view of the land.[14]

Although this view may be alarming, it is important to remember that many human activities have a major impact on land. Besides cities, farming activities have also profoundly altered landscapes.[15] In addition, although the bird's-eye view may seem significant, the visual impact from the ground will greatly depend on the project's installation site: relief, vegetation, population density, etc.

In all cases, it is obvious that the exploitation of gas is much more invasive than that of conventional resources. First of all, unconventional gas resources are much more diffused. The IEA estimates, for example, that the density of ultimate resources in American shale gas is 0.04–0.6 bcm/km^2 compared to values of approximately 2 bcm/km^2 for conventional fields (up to 5 bcm/km^2). In addition to this low concentration of resources, the issue of low permeability (which requires a greater number of drillings to exploit the resource) has to be dealt with. Globally, the exploitation of unconventional gas requires closer drillings on more extended surfaces than for conventional gas.

Therefore, in terms of land use, unconventional gas causes problems similar to those related to solar or wind energies.

Local disturbance

Besides the issue of land use, many other problems are associated with the exploitation of unconventional gas. In particular, for each exploitation site, drilling operations are a major source of sound and light pollution. Each horizontal well requires one to two months of drilling, 24 hours a day. An exploitation site with six horizontal wells will therefore require six to twelve months of drilling. Given that it is necessary to reproduce the exploitation sites at a density of between one and four sites per km^2, there is potential for considerable disturbance caused to local populations.

Along with the disturbance associated with drilling operations, the exploitation of shale gas requires a greater number of lorries. The creation of a single exploitation site would need between 4,300 and 6,600 lorry trips. Besides the local disturbance, this increased traffic might require an adaptation of road infrastructure. Some US States have consequently raised special taxes on gas operators to finance the repairs of road infrastructure.

In the case of the United States, even though some operators have made concerted efforts to limit disturbance (use of less noisy equipment, building of walls to limit sound impact, etc.), the exploitation of these resources remains extremely invasive.

Other impacts

The exploitation of unconventional gas might also cause low amplitude earthquakes. However, it should be noted that induced earthquakes are not specific to unconventional gas and that this phenomenon has already been observed many times in the exploitation of conventional hydrocarbons, during the filling or rapid draining of large dams, and during mining.

Finally, closely compacted drillings and the building of access roads can have major consequences on local biodiversity.

For example, the exploitation of tight gas at the Jonah Field in Wyoming is accused of having caused a massive decline in some bird populations (the sage grouse, for instance).

> The exploitation of unconventional gas calls for the creation of exploitation sites at very regular intervals (1–4 sites per km^2). On each site, intensive operations (drilling, lorry traffic) take place for 6 to 12 months. Globally, even though concerted efforts can be made to reduce these impacts, the disturbance remains significant.
>
> This issue may seem relatively insignificant in sparsely populated areas as in some US States. On the other hand, in more densely populated areas (on the north-east coast of the United States, or in Europe), it is already becoming a major braking force on the development of the resource.

---

(14) For example, drillings at the Barnett Shale site located north of Fort Worth, Texas [Lat: ~33,12; Long: ~-97.38] (http://goo.gl/maps/1pXn2) or at the Marcellus Shale site in the Allegheny National Forest of Pennsylvania [Lat: ~41,50; Long: ~-79,19] (http://goo.gl/maps/BzunU). Each white spot corresponds to an exploitation site.

(15) For comparison, a bird's-eye view of farming activities can also have an impressive impact: http://goo.gl/maps/02LFD or http://goo.gl/maps/C68YA, for example.

7 I Viewpoint of various stakeholders

7I1 Regulations

Positions on the exploitation of shale gas vary from one country to another, from prohibiting shale gas exploitation, to moratoriums, to authorising it. If the exploitation of this resource were to increase, numerous regulations would emerge to control practices and minimise environmental and social risks. However, it should be noted that increasing controls would lead to delays and costs relating to the recruitment and training of experts able to inspect the installations and evaluate risk.

Country	Main regulations
UNITED STATES The United States represents 75% of world unconventional gas production.	Regulations controlling the exploitation of shale gas differ from one US State to another. Nevertheless, as a general rule, these regulations remain flexible and have clearly contributed to the shale gas boom in the United States. First of all, it should be noted that in the US, landowners possess the mining resources located under their ground, contrary to French law, for example, which stipulates that, from the moment there are mining resources contained under their ground, these resources do not belong to the landowner, but to the State. This US feature allowed exploitations to rapidly develop as landowners benefitted from exploitation revenues of their subsoil. On the other hand, historically, underground injections for hydraulic fracturing were never subject to regulation, i.e., they were not governed by the Safe Drinking Water Act. In 1997, the US Court of Appeals of the 11th Circuit declared that the hydraulic fracturing used for the production of coalbed methane in Alabama was indeed an underground injection and should have come under the Safe Drinking Water Act. As a consequence of this legal decision, a study was conducted by the US EPA on the risks to drinking water associated with hydraulic fracturing. In 2004, the EPA declared that the risks were minor, and in 2005 the Energy Policy Act gave details on the definition of underground injection by explicitly excluding hydraulic fracturing without diesel. Note that New York State, which possesses large shale gas reserves, decided on a moratorium in December 2010, prohibiting the use of hydraulic fracturing techniques. According to the New York State Governor's statements, this moratorium, still in force, may shortly be terminated.
CANADA Canada represents 15% of world unconventional gas production.	Quebec decided on a moratorium on hydraulic fracturing pending a complete report on the environmental impact of shale gas exploitation. Exploration work may continue, but without recourse to hydraulic fracturing. In the rest of the country, hydraulic fracturing is authorised.
FRANCE No site currently in exploitation. France would be, with Poland, the European country with the largest shale gas resources.	Since June 2011, France has prohibited the use of hydraulic fracturing. This decision was confirmed by the new government in June 2012.
POLAND Exploitation under development. Poland would be, with France, the European country with the largest shale gas resources.	The Polish government is thinking about tax incentives to favour the development of shale gas.
CHINA Exploitation still hardly developed. Very large potential reserves.	In 2011, the Chinese government's 12th five-year plan gave the green light for the exploitation of shale gas.

7I2 Industry

The gas and oil industry stresses the positive aspects of unconventional gas exploitation, while acknowledging the existence of minor environmental risks. Casing defects are considered to be the main risk (even though they also exist on a smaller scale for conventional gas) due to the multiple drillings needed for unconventional gas. Hydraulic fracturing, as such, is not considered to be a major challenge by the industry, as it is a proven technique used since the 1940s in conventional hydrocarbon drillings.

Moreover, the industry frequently emphasises that the chemical products used represent only a small percentage of the injected solution (<1%) and water volumes can be reduced by treatments and by concerted R&D efforts (e.g. electric arc, fracturing by propane, without water and without chemical products). Still, according to the industry, the use of shale gas offers advantages in terms of global warming and facilitates the transition to a low-carbon economy.

7I3 Society

Conversely, a large number of NGOs and society activists are strongly opposed to unconventional gas exploitation. The documentary 'Gasland', released in 2010, contributed notably to the controversy by filming an American citizen living in a shale gas exploitation area setting fire to his water tap, thereby indicating the possible methane contamination of water resources.[16]

The arguments most often put forward by society are:

- ➜ The volume of water necessary for hydraulic fracturing is enormous.
- ➜ The chemical products used in hydraulic fracturing present soil and water table pollution risks that can lead to health problems.
- ➜ The exploitation of shale gas destroys the countryside due to the multitude of wells to be drilled and the road infrastructure to be built.
- ➜ The large number of lorries needed to transport the water (clean and waste) and other materials and equipment disturb residents (noise pollution and road accident risks).
- ➜ Unconventional gas has a negative impact on the fight against climate change. In particular, the development of this resource will slow down the boom in renewable energies and the implementation of energy efficiency measures.

The major differences between the diverse regulations and viewpoints of stakeholders clearly show the highly subjective character of the evaluation of this technique. It seems very unlikely that a consensus will emerge on these topics, even in the medium to long term. Natixis Asset Management’s position, outlined at the beginning of this study, is based on various viewpoints and is susceptible to change over time, based on new scientific data.

---

(16) The film’s images and in particular the fire and faucet scene are available on the film’s website: http://www.gaslandthemovie.com/about-the-film/media-kit.

Appendix 1 – How are hydrocarbon reserves (gas, oil, coal) defined?

In general, there are three types of reserves in identified reservoirs:

Proven reserves (1P or P90)

Proven reserves are described in terms of volumes of already discovered gas, oil or coal and for which it is estimated that there is a chance that 90% will be extracted under current economic and technological conditions. Only these proven reserves are systematically published by the industry.

Proven + probable reserves (2P or P50)

Proven + probable reserves correspond to the proven reserves to which are added volumes of already discovered gas, oil or coal for which it is estimated that there is a chance that 50% will be extracted under current economic and technological conditions. The amount of these reserves is not systematically published, but it is generally on the basis of a calculation of these reserves that the industry decides whether or not to exploit a field.

Proven + probable + possible reserves (3P or P10)

Similarly, proven + probable + possible reserves take into account the additional quantities corresponding to volumes of already discovered gas, oil or coal for which it is estimated that there is a chance that 10% will be extracted under current economic and technological conditions.

Given their definition, these reserves are habitually being constantly re-evaluated. Although exploitation reduces reserves, various factors can increase their size.

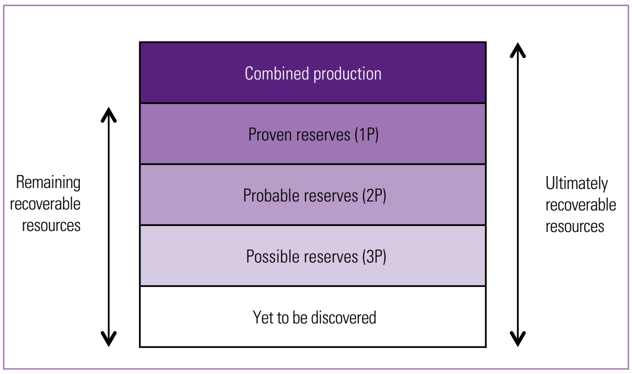
In particular:

- New fields can be discovered and exploited.
- Extraction techniques can be improved, which increases the hydrocarbon recovery ratio.[17]
- Economic conditions can change. In the case of oil, for example, profitable reserves for a barrel at $100 are much more significant than for a barrel at $20.
- For oil, since the OPEC countries' production quotas (⅔ of world oil reserves) are set according to their proven reserves, it is in the interests of these players to change the estimation of their reserves to adjust their production. The problem is the same for private players, for whom the amount of reserves is an important parameter for the company's valuation.

To quantify the hydrocarbons which will be exploited on the ground, the term 'ultimate resources' is used. These ultimate resources correspond to the 1P, 2P and 3P reserves, plus the resources yet to be discovered. The remaining ultimate resources correspond to these ultimate resources minus what has already been produced.

Note: ultimate resources must not be confused with resources in place. Resources in place correspond to all the hydrocarbons contained in reservoirs, regardless of the economic or technical possibility of exploiting them.

This classification applies to conventional and unconventional gas, oil and coal resources.



---

[17] *For conventional oil, for example, this recovery ratio is, on average 35%, with very large variations depending on the fields. For conventional gas, the recovery ratio is generally close to 80%.*

Appendix 2 – Can shale gas emit more CO_2 than coal?

In 2011, researchers from Cornell University, one of the most prestigious American universities, published a study on the impact of shale gas exploitation on climate change (Howarth R. W., 2011).
The main conclusion of the study is that shale gas has a greater impact on climate change than coal. The study also estimates that, in some cases, this conclusion can also apply to conventional gas.

This conclusion was strongly criticised by industrialists[18] for several reasons:

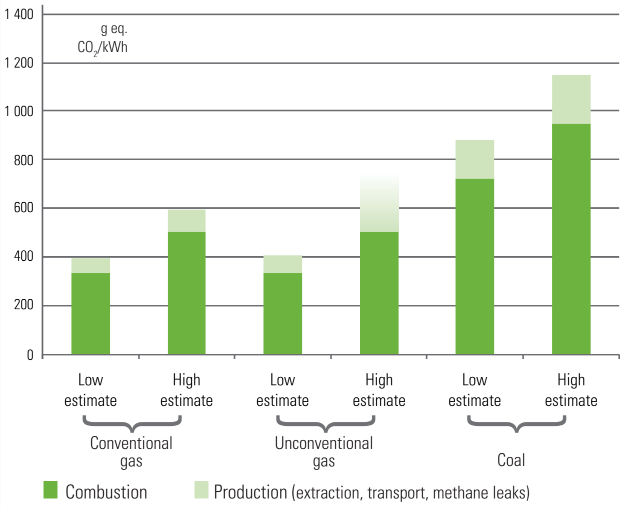
➜ The study insists on taking into account the Global Warming Potential (GWP) over 20 years, while almost all studies use a GWP over 100 years. However, this choice is not without its consequences because, in the study, it multiplies the impact of methane leaks by three. Taking into account this GWP over 20 years, shale gas has an impact between 20% and 100% higher than coal. The study estimates that the potential in 20 years is more relevant because it is necessary to greatly reduce greenhouse gas emissions in the coming decades. However, this choice does not correspond to the standard practices of environmental evaluations.[19]

➜ Even in the case of the use of a GWP over 100 years, the study concludes that unconventional gas has an impact equivalent to that of coal. This conclusion was similarly strongly criticised. The study estimates that only the well creation stage generates the differences of methane leaks between conventional gas and shale gas. These additional leaks do not increase the CO_2 footprint of shale gas by more than 20% compared to conventional gas. Other methane leaks are the same for conventional gas and shale gas.
An important point is that, in this study, conventional gas has a much more unfavourable footprint than in most other studies (-15% compared to coal in the Cornell study, while in most of the studies, for example, the French ADEME, the CO_2 footprint is -40%). This difference is due to a very high leakage ratio over the entire life cycle (extraction, transport, combustion) in the study (2–6%), while the generally accepted values use a much lower ratio (~1%).

Finally, other factors increase the gas's footprint, such as taking into account GWPs above the values recommended by the IPCC or the comparison of both energies per energy content without taking into account the efficiency of electric power plants, which is the main use for which both of these energies compete.

Globally, the revelation of this study is in the measurement of additional leaks linked to shale-gas-specific extraction processes. However, these estimations are based on very few production sites and the data is strongly contested by industrialists. Even if these figures were proven, the shale gas footprint would only be approximately 20% higher than that of conventional gas, which remains much better than the environmental footprint of coal.

Figure 19: Estimation of greenhouse gas emissions for the production of electricity (conventional gas, unconventional gas and coal)



- For gas, the high bar sections correspond to power plants with an efficiency of 40%, corresponding to a low estimation of the efficiency of the power plants installed throughout the world; the low bar sections correspond to an efficiency of 60%, corresponding to the highest performing gas power plants.
- For coal, the high bar sections correspond to power plants with an efficiency of 36%, corresponding to an estimation of the power plants installed throughout the world; the low bar sections correspond to an efficiency of 47%, corresponding to the highest performing coal power plants.
** The lighter green section of the high estimation of unconventional gas corresponds to the uncertainty of the existence of additional methane leaks.*

Source: Natixis Asset Management estimation according to ADEME.

In other words, this study questions the CO_2 footprint, not only of shale gas, but also of conventional gas. Since the estimations on conventional gas are counter to most of the reference sources, these values must be approached with caution. However, the approach taken by the Cornell researchers focuses on the uncertainties that prevail on the environmental impacts of gas, considering, in particular, the methodological choices and the uncertainties on methane leaks. This point is being specifically followed up by our extra-financial research team.

---

[18] See, in particular, the American oil and gas producers' site: http://www.energyindepth.org/2011/05/five-things-to-know-about-the-cornell-shale-study/.
[19] The standard choice of a GWP over 100 years is linked to the fact that the United Nations Framework Convention on Climate Change (UNFCCC), in the framework of national inventories, recommends using the global warming values over 100 years.

APPENDICES

Appendix 3 – Companies currently involved with unconventional gas

Country	Company	Shale gas	Tight gas	CBM
Australia	Santos Limited	X	X	X
China	Petro China	X	X	X
	Sinopec	X	X	X
Brazil	OGX Petroleo e Gas	X		
France	Total	X	X	X
Italy	Eni	X		X
Norway	Statoil	X	X	X
Spain	Repsol YPF	X	X	
United Kingdom	BG Group	X	X	X
	BP	X	X	X
	Royal Dutch Shell A	X	X	X
Canada	Canadian Oil Sands	X	X	X
	Sucor Energy Inc.	X	X	X
United States	Anadarko Petroleum Corp	X	X	X
	Apache Corporation	X	X	X
	Chevron Corp	X	X	X
	Conoco Phillips	X	X	X
	Devon Energy Corporation	X	X	X
	Exxon Mobil Corp	X	X	X
	Hess Corp	X	X	
	Marathon Oil Corporation	X	X	X
	Occidental Petroleum Corp.	X	X	
	Quicksilver Resources Inc	X	X	X
	Range Resources Corp.	X	X	X

BIBLIOGRAPHY

ADEME (2010) - *Guide des facteurs d'émissions, chapitre 2*. From www.associationbilancarbone.fr/private/88/field-fichier/guides_facteurs_demissions_v6.1.zip

BP (2012) - *Statistical Review of World Energy*. From www.bp.com/statisticalreview

Chesapeake/Statoil (2008). From http://fotoweb.statoil.com/fotoweb/Grid.fwx?archiveId=5004&search=marcellus

EPA (Nov. 2011) - *Plan to Study the Potential Impacts of Hydraulic Fracturing on Drinking Water Resources*. From www.epa.gov/hfstudy/HF_Study__Plan_110211_FINAL_508.pdf

European Commission. (2007) - *An Energy Policy for Europe*. From http://ec.europa.eu/energy/energy_policy/doc/01_energy_policy_for_europe_en.pdf

GIEC *Changements Climatiques (2007) - Rapport de Synthèse*. From www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr_fr.pdf

Howarth R. W. et al. (2011) - *Methane and the greenhouse-gas footprint of natural gas from shale formations*. Cornell University. From http://graphics8.nytimes.com/images/blogs/greeninc/Howarth2011.pdf

IEA (2009) - *World Energy Outlook*. From: www.iea.org/

IEA (2011) - *CO_2 Emissions from Fuel Combustion 2011, Highlights*. From www.iea.org/publications/freepublications/publication/name,4010,en.html

IEA (2012) - *Golden Rules for a Golden Age of Gas*. From www.worldenergyoutlook.org/media/weowebsite/2012/goldenrules/WEO2012_GoldenRulesReport.pdf

IFP Énergies nouvelles (Dec. 2010) - *Unconventional gas and water*. From www.ifpenergiesnouvelles.com/content/download/70599/1513816/version/2/file/Panorama2011_09-VA_Gaz-non-conventionnels-Eau.pdf

Total (Nov. 2011) - *Unconventional Gas, Resources for the Future*. From www.total.com/MEDIAS/MEDIAS_INFOS/5070/EN/TOTAL-unconventional-gas.pdf

Total - *Exploration and Production -> Animation: The formation of a deposit*. From ://www.total.com/en/our-energies/oil/exploration-production-940839.html

Tyndall Centre (2011) - *Shale gas: a provisional assessment of climate change and environmental impacts*. (Manchester University). From www.tyndall.ac.uk/sites/default/files/tyndall-coop_shale_gas_report_final.pdf

U.S. Energy Information Administration (2012) - *Annual Energy Outlook*. From www.eia.gov/forecasts/aeo/pdf/0383(2012).pdf

TABLE OF ILLUSTRATIONS