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Unconventional Natural Gas

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With the development of extraction technologies such as hydraulic fracturing, the world's vast unconventional natural gas reservoirs have now become accessible and are sought after as a potential new energy source. But their exploitation is also a source of controversy due to the environmental impact of the production techniques. In order to assess whether gas from these resources could play a role in the future energy mix, we need to better understand their specific geological and physical characteristics, as well as the exploitation technologies and their potential risks. From the outset, we should integrate the views of a variety of societal actors and reflect on the role unconventional gas can play in wider energy transition processes.

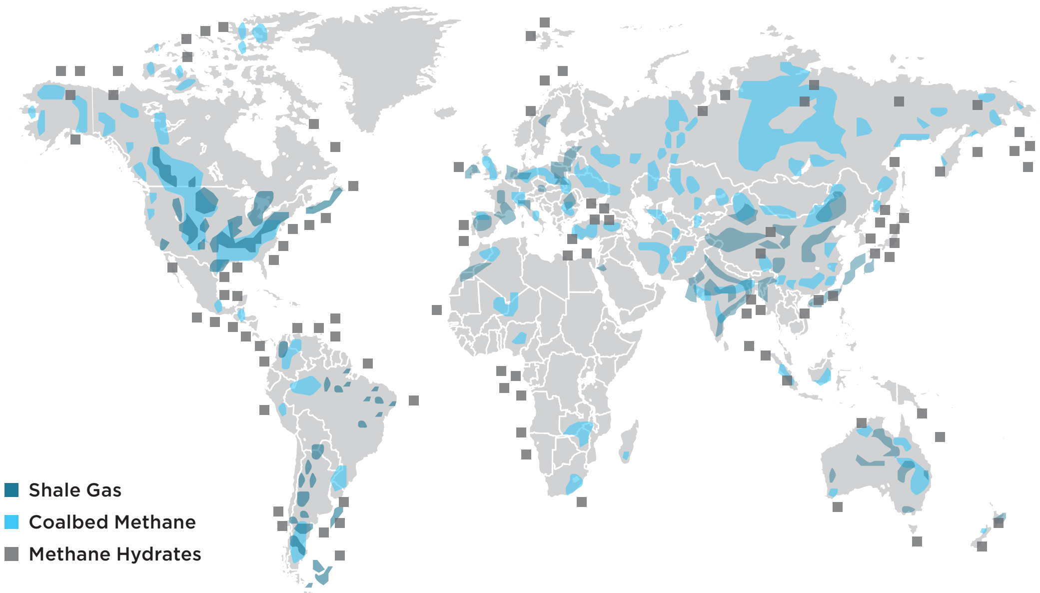

Figure 1: Worldwide distribution of the most significant unconventional gas reserves (based on data from PacWest and the US Geological Survey)

What is unconventional natural gas?

Unconventional natural gas (UNG) is trapped in organic-rich deposits such as shale rocks (**shale gas – SG**) and coal seams (**coalbed methane – CBM**), or in ice (**methane hydrates – MH**). Accumulations are usually found in deep geologic formations (SG and CBM), but can also occur in shallower sediments, for example, in permafrost or in submarine continental margins (MH). Like conventional natural gas, it consists primarily of methane (CH_4).

The term 'unconventional' refers to the fact that the exploitation techniques necessary to release the gas from the formation differ from those used for conventional gas, because the gas is absorbed or trapped in an impermeable source rock (SG and CBM), or bound within a crystal lattice (MH).

Conventional gas is produced by drilling a borehole into a porous, permeable rock formation, which lets gas flow out of the rocks and up to surface. By contrast, gas from shale deposits is produced by *hydraulic fracturing* ('fracking'), where a mixture of water, sand and chemical additives is pumped into the reservoir at very high pressure, creating a network of fractures that allows the gas to escape from the rock. Coalbed methane and methane hydrates also require different exploitation technologies that are specific to their geological characteristics.

Why is unconventional gas being discussed?

Unconventional gas reserves have been attracting interest from industry, science and governments because they represent a very large potential source of energy, with deposits distributed across the world (Figure 1). Currently, unconventional gas is being produced at commercial scale in the USA and Canada (mostly shale gas and coalbed methane), while research and development is ongoing in China, Australia, Argentina, Poland, Romania, Ukraine and the UK (shale gas), and Japan (methane hydrates). The estimated recoverable reserves of UNG (without methane hydrates) are roughly equivalent to the remaining conventional oil and gas reserves (about 400 trillion cubic meters, or tcm)[1]; methane hydrates alone would add another 1,000 to 5,000 tcm. To put this in context, current global gas consumption amounts to 3.4 tcm per year and is forecasted to reach 5 tcm by 2035. UNG is often seen as a way to offset dwindling conventional reserves and an opportunity to substitute gas imports with domestic production and therefore enhance energy security. For example, in the USA more than 90% of the gas demand is currently met by domestic production due to UNG buffering conventional gas. By increasing the availability of gas, the US shale gas 'boom' has led to a reduction in energy prices that has benefitted energy-intensive industries and the petrochemical sector in particular. Low gas prices have, however, begun to threaten the economic viability of the shale gas industry. In the end, it is difficult to comprehensively assess the possible economic benefits of UNG exploitation because they are very country-specific.

The exploitation of UNG reserves also entails a number of challenges and potential risks. Hydraulic fracturing, for instance, is often a source of controversy due to its associated environmental threats, including groundwater contamination, induced seismicity (earthquakes), and fugitive emissions of methane, a potent greenhouse gas. The construction of new wells is often opposed vociferously by local communities and raises a multitude of issues in relation to land use, noise, pollution, etc. In the case of shale gas, the short lifetime of a well requires frequent drilling of new wells to maintain output levels. Because of these concerns, considerable public pressure, and the lack of conclusive scientific assessments, some European countries like France and Germany have put unconventional gas exploitation on hold. This application of the precautionary principle distinguishes the European approach from the American one.

Finally, the compatibility of UNG with climate policies is also a matter of debate. Natural gas is considered to be the 'cleanest' fossil fuel, emitting less than half the amount of CO_2 per unit of energy generated compared to coal. Hence, substituting coal with gas in the energy mix could lead to a reduction in CO_2 emissions, as has been partly the case in the USA. Some observers also point out that the flexibility of gas-fired power plants could make them a suitable option for supporting renewable energy sources with back-up energy generation.

Yet, natural gas use for energy generation is still a source of GHG emissions and could perpetuate our dependency on fossil fuels. Unconventional gas exploitation could also negatively affect the further deployment of renewables, for instance, by reducing their competitiveness or by diverting investments and subsidies. Therefore, the possible role of UNG in the transition to a more sustainable energy system remains an open and controversial question.

What are the main kinds of unconventional gas and what risks do they pose ?

Shale gas

Reserves

Shale gas occurs in sedimentary basins with significant organic-rich shale formations, where methane is mostly adsorbed on organic remains. The very low permeability of the source rock does not allow for considerable gas production from the formation without using the hydraulic fracturing technique (Figure 2b). Worldwide, technically recoverable shale gas reserves are estimated to be around 200 tcm[2], with approximately 16 tcm in Europe. However, there is still a high degree of uncertainty with regard to total reserves since only a few countries in the world have undertaken exploration.

Production

Over the past decade, the combination of horizontal drilling and hydraulic fracturing has made it possible to access large volumes of shale gas. The 'fracking fluid' used for fracturing is composed of water mixed with approximately 5–10% sand and 0.1–0.5% chemical additives, and is pumped at high pressure into the well to create cracks in the shale formation. The sand keeps the cracks open, while natural gas migrates into the well and then to the surface together with a mix of injected and brine water (flowback water). A typical multi-stage fracturing operation, which is usually performed only once at the beginning of a well's lifetime, requires between 11 and 30 million litres of water.

In the USA and Canada, the extensive use of this technology, particularly from 2008 onwards, has led to a rapid increase in shale gas production. Today, 40% of the natural gas consumed in the USA is obtained from shales. In Europe, the situation varies from country to country with some moving towards commercial production (Poland, Romania, Ukraine, UK), while others have put exploration on hold (France, Germany). In late 2014, the German government announced that a law could be adopted soon that will in all likelihood prohibit fracking for commercial purposes and only allow scientific tests with very strict environmental protection requirements.[3]

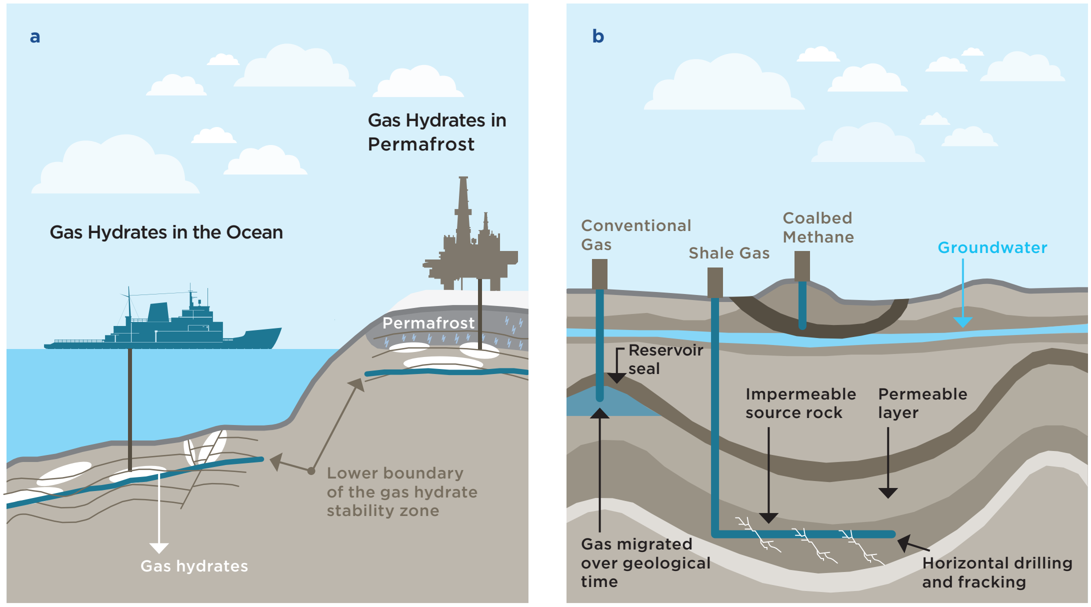

Figure 2: Simplified geological profile of gas reservoirs and exploitation methods for methane hydrates (a), conventional gas, shale gas and coalbed methane (b)

Risks and uncertainties

The main environmental risks related to hydraulic fracturing are groundwater pollution, induced seismicity and methane emissions. Fracking fluid may contain potentially harmful chemicals that might affect groundwater and soils. Moreover, the flowback water can also contain additional natural toxic elements (such as heavy metals) that come from the shale formations. Proper well completion techniques could minimise the risk of contamination through the wellbore and ensure that all the water that flows back up is collected at the surface (30–70% of the initially injected water remains in the shale layers). At the surface, the contamination risk is greater due to possible uncontrolled spills, as has been the case in some locations in the USA. Depending on local regulations and costs, the collected water is either treated for re-use in fracking operations or disposed of. 'Cleaner' fracking fluids are being developed by industry, but their use is contingent on the regulatory framework and its degree of enforcement.

There have been cases of fracking-induced low-scale earthquakes (e.g. in 2011 in Blackpool, UK). In areas with natural seismic activity, hydraulic fracturing is likely to trigger these events, and should therefore be prohibited. In areas with low natural seismicity, proposed risk management measures include monitoring microseismic events during the fracking phase and halting operations when their magnitude reaches pre-determined levels (e.g. 0.5 on the Richter scale).

Finally, methane emissions during production are an issue in both unconventional and conventional gas extraction and depend mostly on how carefully processes such as field production, processing, storage, and distribution are carried out. For shale gas, fugitive emissions are estimated to range between 1% and 8% of total production.[4] Since the greenhouse effect of methane is several times higher than that of CO_2, these fugitive emissions could offset the net climate benefits of burning gas instead of coal.[5] The risks of methane leakage could be reduced by using a green completion technology for the water/gas separation step and by implementing leak-detection and -repair systems throughout the life cycle.[6] In practice, the use of these technologies is subject to costs and regulatory requirements.

Coalbed methane

Reserves

Coalbed methane (CBM) refers to methane gas that is trapped in coal and could be recovered from unmined or unmineable coal seams. The vast amounts of coal in the various basins around the world have generated significant amounts of CBM: up to 50 tcm worldwide.[7] Given the large internal surface area of coal, these reservoirs can store up to six or seven times more methane than a comparable conventional natural gas reservoir.

The largest reserves lie in Russia (17 tcm), China (10 tcm), Australia (8 tcm) and North America (7 tcm). In Europe, there could be CBM resources of 2.5 tcm, but these extimates are uncertain because reserves are poorly quantified and mapped. In 2012, the European Commission began to develop a database of CBM resources in Europe (EUCORES).

Production

Although we have known about CBM since the early days of coal mining, separate commercial CBM production has only begun recently. The global market for CBM is led by North America (78.9% of the market in 2011), followed by Asia Pacific (Australia, China) and Europe (UK).[8]

The United States was the first country to commercially produce CBM in 1989. Since then, recovered volumes have considerably increased: from 2.5 billion cubic metres (bcm) in 1989 to 43.5 bcm in 2012. In Europe, the UK is the only country where CBM wells have been drilled.

The extraction technology for CBM usually differs from shale gas: part of the groundwater that infiltrates the coal is pumped out, which causes the pressure to gradually decrease and leads gas to migrate naturally to the surface through the well. Because CBM formations are usually more permeable (compared to shale gas), hydraulic fracturing is rarely necessary, except in cases where the seams are particularly deep and/or thick.

Risks and uncertainties

CBM extraction produces significant volumes of waste water, and water disposal and depletion are the main environmental concerns. The water produced varies from well to well and may contain dissolved substances such as salts, chemicals, heavy metals and radionuclides. Water treatment and disposal solutions (e.g aeration, filtration) are available, but the high costs involved hinder their widespread implementation.

Methane leakage also occurs during CBM production. A reliable data set for fugitive emissions by country does not exist yet, and current estimates range from 1% to 4.5% of total production.[9]

Methane hydrates

Reserves

Methane hydrates (also called methane 'clathrates') are by far the biggest source of unconventional gas on our planet, with estimated reserves in the range of 1000–5000 tcm. They are crystalline ice-like solids with molecules of methane in pore spaces and are stable at specific temperature and pressure levels. Most marine MH deposits, which represent 95% of all reserves, are found in superficial layers of continental margins at between 300m and 1200m below sea level and can be up to 500m thick. The remaining 5% occur in permafrost soil (Figure 2a).

Production

Production techniques alter the temperature or the pressure in methane hydrate deposits in order to liberate the gas within. As yet, gas hydrates are not being commercially produced, and future production depends on suitable deposits, extraction costs and technology. Exploitation methods are still in their infancy and face many technical challenges. Two that have been used so far are:

- ***Thermal stimulation:*** hot water is injected into the well, which triggers hydrate instability and gas release. This method was used during onshore tests on permafrost deposits at the Mallik site in Canada in 2001/2002 and again in 2008. It demonstrated that gas production from hydrates is technically feasible.

- ***Depressurisation:*** the pressure in the reservoir is decreased by pumping out some of the water or free gas that exists within and under the MH formation. This destabilises the hydrates and frees the gas. This method was used in 2013 at the Eastern Nankai Trough in Japan during an offshore test.

Risks and uncertainties

Offshore methane hydrate production is a subject of ongoing debate owing to a number of potential environmental risks that are not yet fully understood (e.g. possible dispersion of toxic substances in the water column). In particular, gas extraction from these reservoirs could lead to seafloor instability, which could trigger large uncontrolled releases of gas and provoke undersea earthquakes. It is worth noting that this instability can also be attributed to other natural or anthropogenic causes, such as submarine landslides and rising temperatures. Indeed, global warming could affect permafrost reservoirs due to ice melting, and marine deposits due to changes in deep-sea temperatures. Currently, there is no scientific consensus on the likelihood of such events occurring and on what scale they might be.

[1] *International Energy Agency (IEA),* World Energy Outlook 2013. *Resources in some Eurasian and Middle Eastern regions are not well known. More generally, resource estimates are often uncertain and, especially in countries where exploration has not taken place, actual reserve levels could be significantly higher/lower.*

[2] Ibid., 1.

[3] *Federal Ministry for the Environment and Federal Ministry for Economic Affairs,* Überblick über die geplante "Fracking"-Regelung, *July 2014.*

[4] *Howarth et al.,* A bridge to nowhere: methane emissions and the greenhouse gas footprint of natural gas, *in: Energy Science and Engineering, 2(2): 47–60, 2014.*

[5] *Recent studies indicate that this could be the case when fugitive emissions exceed 2.4–3.2% of total well production. See Alvarez et al.,* Greater focus needed on methane leakage from natural gas infrastructure, *in: Proc. Natl. Acad. Sci. USA 109: 6435–6440, 2012 and ibid., 3.*

[6] *International Energy Agency,* Golden Rules for a Golden Age of Gas, *May 2012.*

[7] Ibid., 1.

[8] Coal Bed Methane Market – Global Industry Size, Market Share, Trends, Analysis, and Forecast, 2010–2018, *Transparency Market Research, June 2014.*

[9] *Stuart Day et al.,* Fugitive Greenhouse Gas Emissions from Coal Seam Gas Production in Australia, *CSIRO, October 2012.*

SUMMARY

- Global gas supply and demand is expected to increase in the coming decades. Estimates of unconventional gas reserves are still uncertain for many regions and countries, but they are likely to be at least equivalent to the remaining conventional reserves (excluding methane hydrates).

- Gas production from shales and coalbeds is already a reality in some countries. Methane hydrate exploitation remains a distant prospect.

- The production technologies are a source of many potential environmental risks and concerns, in particular water management issues and fugitive emissions.

- Measures for managing and mitigating these risks, including lifecycle emissions, are being developed. But further research into many issues is necessary.

- Moreover, these measures will require strict regulatory and enforcement frameworks to ensure their successful implementation.

- Finally, the possible role of unconventional gas in the energy transition is also contingent on questions of economics, social acceptance and climate-policy targets. In this respect, key issues are the risk of entrenching current fossil path dependencies and compatibility with the deployment of renewables.

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