Shale Gas and Hydraulic Fracturing

Framing the Water Issue

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Executive Summary

The emergence of shale gas and shale oil has quickly changed the landscape of opportunities for energy provision and security in different regions of the world. Difficulties in assessing the actual quantity of existing global shale hydrocarbon reserves produce opposing views on whether the world is on the verge of a "shale gas revolution" and, if it is, how long it could last. Some argue that shale gas may constitute a backbone of energy supply for specific countries for decades to come, while others say the peak may have passed already.

Despite this, some nations – such as the USA – have already started an ambitious exploitation of this comparatively cheap energy resource, providing new and favourable conditions for domestic energy supplies and costs, and creating new jobs in the booming shale industry.

For various reasons other countries have not taken the plunge, despite assessed quantities of shale resources. These reasons include fear of possible severe environmental impacts. These are often associated with shale gas extraction accomplished through the technology known as hydraulic fracturing, or "fracking"; evidence of the impacts is emerging in places where intense, unregulated fracking takes place.

Many of these impacts make themselves felt in water resources. Fracking is a water-intensive activity, and as the reserves are often found in dry areas extraction poses additional challenges in what are often already water-stressed environments. The vast water quantities needed over the life span of a shale gas well, where water is used to fracture rock under high pressure, pile further stress on local fresh water sources which are already needed for many different purposes. At times when water supplies are running short in a specific area it has to be transported to the fracking site from afar.

Water quality is also under threat from fracking as well as the quantity available. Many chemicals used in the fracking fluid (the composition of which is often protected for commercial confidentiality reasons) have increasingly been found to be harmful both to the environment and to human health, yet poor regulations and legislation governing fracking often allow accidents which contaminate surrounding water sources.

There is a need for greater responsibility, through developing codes of conduct and regulatory systems governing fracking so as to protect water resources and the environment. It should be adopted by all nations currently exploiting or liable to exploit shale resources as part of their energy supply.

Introduction

The supply of services involving water, energy and food, fundamental to sustain life, all have a common factor: the availability and quality of fresh water resources, or the lack of them. Some of these links can be more obvious than others. They bind the resources intricately together, so that the development of one can have immediate effects on the ability to produce another. Water constraints almost invariably influence both energy and food production.

The need to understand these connections has never been more urgent. In the next few decades the world population is expected to grow by two billion people (UNFPA, 2013), world energy consumption is predicted to grow by 56 per cent (EIA, 2013), and agricultural production will need to go up by 60 per cent (FAO, 2013). At the same time global water demand is predicted to grow by 55 per cent and approximately 40 per cent of the world's people are predicted to be living in areas of severe water stress (WWAP, 2014).

Understanding competing demands for water and how they are related is critical to meeting emerging challenges. Comparatively less explored and researched, the evolving and dynamic landscape of how energy is linked to water (the water-energy nexus) has rapidly become an area of interest. On a global level agriculture is still the major water user but regional patterns are quickly changing. In developed economies (EU, US) water withdrawals for energy are at 40 per cent of demand and approaching 50 per cent. Similar patterns can be seen in emerging economies (IEA, 2012).

Major changes in the energy sector can therefore also be expected to affect the state of water resources at different levels, so these must be carefully assessed. Few trends in energy development are currently as

Photo: iStock

talked about as the possible shale gas revolution. The concept captures the possibility of a probably game-changing expansion of shale-derived natural gas in the global energy mix. The wealth of shale resources globally, the cost-effectiveness of shale gas compared to many other fuels (not least other fossil fuels), combined with precision extraction methods, has positioned shale gas in the forefront of a potential boom of natural gas exploitation worldwide. However, the opportunity shale gas brings also brings many questions yet unanswered, not least about its extraction method of hydraulic fracturing or fracking.

These questions include the climate impacts of methane leaks during fracking operations and of CO_2 released when methane is combusted are still relatively unknown, as well as the risks of contamination and depletion of water resources.

Reactions to the uncertainties surrounding shale gas and fracking vary widely with some countries hesitating to exploit the resource while in other nations more or less unregulated shale gas industries and activities expand rapidly.

This report aims to compile the available information on shale gas and fracking, especially in the light of growing concerns about the consumption of water as well as the serious pollution risks. Shale gas has been found in many areas with water scarcity and contamination of the injected and returned fracking water makes the operations highly controversial. On the basis of this information, the report presents policy advice and guidance to aid decision makers wishing to steer a way through the current uncertain landscape.

Note to the Reader

The report is primarily the product of a literature review, and of meta analyses of raw data.

The comprehensive review of recent literature has provided the bulk of information from carefully screened sources.

Desktop searches have added complementary information providing relevant snapshots of current issues that might not be covered in the broader scientific literature, including the published views of many in the fracking industry.

Analyses of raw data from several carefully selected, credible sources (such as Clark, 2012; IEA, 2013; EPA, 2012; NETL, 2013; WEC, 2013) describing comparative values of water use in related processes have helped the authors to determine probable scales of water resource use and the impacts connected to the fracking process.

Though the report is global in focus, the reader should know that many references in it refer to the USA and its shale gas industry. This is largely because shale gas operations in many ways have developed much further in the US than in other parts of the world, and so it is also where many impacts can be seen and analysed. Much of the data, though, comes from official sources and national laboratories.

The conclusions drawn in the report, and the recommendations made, are those of the authors alone.

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Shale Gas – A Natural “Tight Gas”

“Tight gas” refers to sources of natural gas (almost entirely methane) that are quite old and are locked in layers of impermeable hard rock (shale formations). Over time these layers have been exposed to high pressures and temperatures and compressed, leading to decomposition of trapped organic material and recrystallization and cementation of the material between generated pockets of gas. The challenge is to reach these pockets and open them up so that the trapped gas can reach the wellbore more easily. Tight oil is also produced by these processes.

‘Tight gas’ also refers to natural gas found in sandstone or limestone formations which are atypically impermeable/nonporous. Lack of permeability means that the trapped gas cannot travel easily through the formation and be extracted economically using conventional vertical well-drilling technologies. Other production methods are required if this trapped gas is to compete in natural gas markets, and this is the “revolution” that fracking – the combination of conventional vertical drilling and horisontal drilling at depth – has made possible.

Drivers for Growth

Global drivers

There have been a lot of surprises in the history of energy. The OPEC oil embargo of 1973-74, and the Iran-Iraq war of 1979 raised oil prices. Few predicted the prices' sudden collapse just a few years later. The collapse drove many countries into an economic tailspin. Just a decade or so ago, some companies invested tens of billions of dollars in natural gas import terminals in the US. They turned out not to be needed after all when the shale boom led to an unexpected domestic natural gas bonanza. Now those terminals are being converted to export US gas. Shale has transformed the energy map in the US in a very short time. In 2005 less than 5 per cent of US gas production came from shale fields. As late as 2006 many US business and government leaders believed the country was running out of fluid forms of fossil fuel. Yet by 2013 US oil production had increased by 50 per cent, compared with 2005. The perspective in 2014 is that the US can produce more than 11 million barrels per day by 2020. It is predicted to surpass both Saudi Arabia and Russia as the world´s top oil producer (IEA, 2013).

Financial drivers

The economic incentives are enormous. The development of shale oil and gas not only has the potential to create a lot of jobs - it has already done so in Montana and North Dakota (National Journal, April 14, 2014 – "How Many Jobs Does Fracking Really Create?", Clare Foran) and will also keep energy prices down. In the US, in contrast to most other countries, including the EU and East Asia, natural gas production by means of fracking has been so effective that prices have plunged, giving consumers and industry a financial break (IEA, 2013). The country has replaced almost all imports of high-quality African oil with the booming production of its own shale oil fields. Already by 2013 the US had become the world's largest producer of natural gas because of shale gas obtained by fracking.

Photo: iStock

In Europe (outside Russia) there is a lot of shale gas. However, Europe has a high population density and more restrictive rules than the US regulating how to explore for oil and gas. For example, in the UK underground mineral rights do not belong to the landowner, as they often do in the US, but to the British Government. France, Bulgaria, and parts of Spain have already banned fracking, concerned about the environmental risks. Other European countries, such as the UK and Poland, show strong interest in shale oil and gas. Yet Europe had just 17 rigs operating in 2013, while the US had 1,700.

Political drivers

At a time when Russia is considered a renewed threat in the West and the Middle East is in turmoil, a geopolitical energy shift is underway with the potential to make the world less energy-reliant on those trouble spots. Recent events in Ukraine have prompted EU countries to consider alternatives for gas supplies from Russia, not only to help Ukraine but also to become less vulnerable to political pressure from the Russian Federation. At the same time Russia, whose economy is highly dependent on revenues from energy exports, needs the income from its gas. The US exported 268,000 barrels per day (b/d) of crude oil in April (the latest data available from the US Census Bureau; see www.eia.gov), the highest level of exports in 15 years. Exports have increased sharply since the start of 2013.

The Evolving Global Energy Landscape and the Emergence of Shale Gas

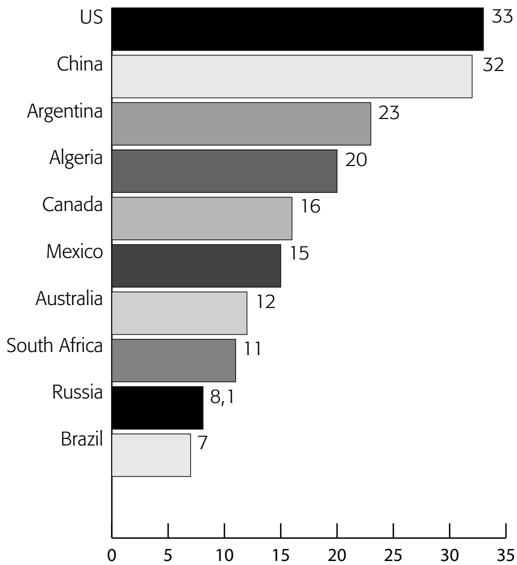
Global shale gas resources - overview

Among the more prominent energy security arguments for shale gas is that it is available globally. Unlike conventional fossil fuels which are predominantly concentrated to a few regions of the globe, shale gas can be exploited in many countries. For them, this constitutes a unique opportunity to shore up their own supplies and limit their dependence on energy imports in times of geopolitical uncertainty. This is obviously important for countries with massive energy needs and high consumption levels, both current and predicted.

Interesting patterns emerge from considering current and future energy demand, shale assets and areas of water scarcity together.

Major shale formations assessed as technically exploitable are found in areas including the south and north-eastern US, China, Brazil, North Africa, large parts of Europe, South Africa, Australia, Russia and Canada (EIA, 2013). The US and China alone each has documented and technically exploitable resources of around $30{\cdot}10^{12}\ m^3$ (more than 1,000 cubic feet, Tcf). Coincidentally several of these nations also make the top ten list of the world's energy consumers, including China, the US, Canada, Brazil and Russia (Enerdata, 2014). Another layer of analysis – of areas already experiencing or approaching physical and/or economic water scarcity – many of the same regions re-appear, some of them showing all three of the indicators mentioned above – plentiful shale assets, water scarcity and huge energy demand (WWAP, 2014). In addition there are areas where severe threats to water quality persist, limiting water use for different purposes, which are not represented sufficiently in conventional water scarcity mapping. This is the case in parts of Europe, China and Russia, as well as North America. Two-thirds of the assessed, technically recoverable shale gas resource is concentrated in six countries – the US, China, Argentina, Algeria, Canada and Mexico (EIA, 2013). The top ten countries for shale potential account for over 80 per cent of the currently assessed, technically recoverable global shale gas resources. Similarly, two-thirds of the assessed, technically recoverable shale oil resource is

Figure 1. Top 10 countries with technically recoverable shale gas resources 10^{12} m^3.



The world total is $207 \cdot 10^{12}$ m^3. To convert the volumes to Tcf (trillion cubic feet) multiply by 35.25.

Source: Energy Information Administration (EIA) estimates (US Department of Energy, 23 October, 2013).

concentrated in six countries- Russia, the US, China, Argentina, Libya and Australia.
To date most shale gas formations have been found onshore. Estimated recoverable resources are shown in Figure 1.

Shale gas is clearly widely distributed. China is the only nation outside North America that has extracted commercial quantities of shale gas to date, although the amount is less than 1 per cent of its total natural gas production (2012). Comparable numbers for the US and Canada are 39 per cent and 15 per cent respectively. To put them in perspective, current annual global consumption of natural gas is about $3.4 \cdot 10^{12}$ m^3 (120 trillion cubic feet).

If shale exploitation in places like Argentina, China and Russia, which have so far lagged behind North America, took off, there would be significant new sources of oil and gas on the world market. This in turn would influence energy prices just as it did in the US.

Economy and market aspects

The economics of oil and natural gas extraction are challenging: deep water oil drilling, oil sands extraction and shale drilling are all expensive and require high market prices to justify extraction. Most of the easy-to-drill oil may be gone. But if North America produces too much oil too quickly, and if exports surge from Iraq and Iran, then global oil prices could soften considerably.

The costs of extracting the oil sands and environmental concerns over the process have dampened economic expectations. Even so, capital spending by several major oil companies on oil sands is rising. One concern is that an oil oversupply caused by the fracking of shale could develop in the US which could depress prices so much that it would be difficult for producers to justify sustaining production. The price of fossil fuels has often changed in unexpected ways. Just a couple of years after the natural gas drilling boom in the US took off, the subsequent supply caused prices to drop so sharply from 2009 to 2012 that producers were forced to stop drilling in several shale fields until they partly recovered in 2014. Because markets for natural gas are much less globally integrated than world oil markets – oil is easier to transport than gas – the prices for shale gas vary markedly in different countries.

What makes shale drilling particularly challenging is that wells produce most of their oil and gas in the first years of production, eventually requiring more and more redrilling and new drilling in lower-quality zones of the fields.

It is important to understand the distinction between the terms “resources” and “reserves”. The first refers to the total shale gas that may exist in an area and is technically recoverable in principle, while the second is the amount that may be economically recoverable. The amount of reserves depends on geology and technology, but also on political and social factors. This in turn makes it difficult to assess the actual quantities that can be used over time, and therefore estimates of how long shale gas assets can last in a specific region can differ widely.

The International Energy Agency (IEA) believes that the US may be capable of becoming energy-independent in future decades thanks to its shale oil and gas reserves. However, some analysts suggest that the US consumes too much for that to happen, while others claim that the promises of America's shale reserves have been vastly overstated (Inglesby *et al.*, 2012).

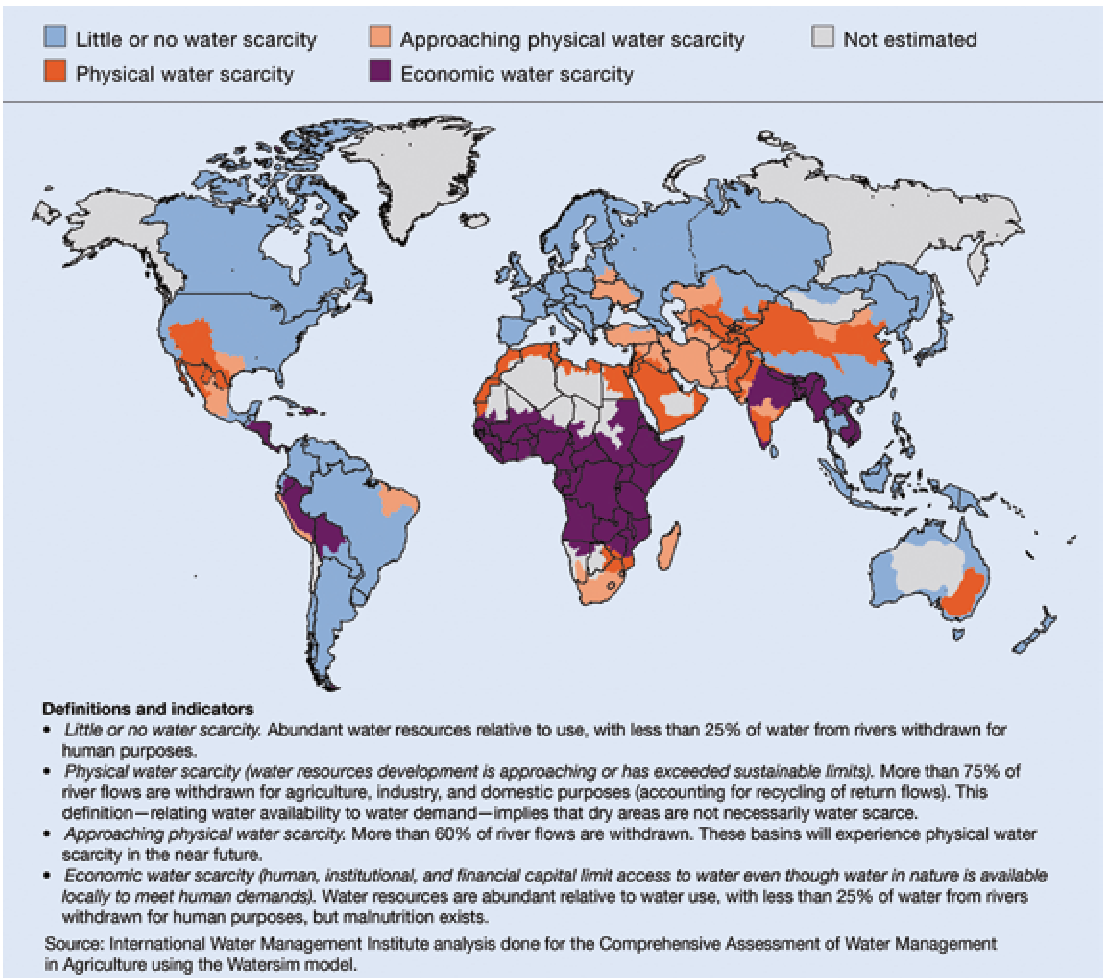
Whatever the amount of shale gas that may exist, public opinion needs to be able to accept that it can be extracted safely as well as cost-effectively. The price of other fossil fuels will determine what becomes economically recoverable, so even if shale gas is technically recoverable it may stay below ground if the price is not right.

Wang-Krupnick (2013) suggest that the key question for policymakers in countries attempting to develop their own shale gas resources is how to generate a policy and market environment in which firms have the incentive to make investments. In the US it has been possible to lease land and mineral rights across large areas. This was a powerful incentive to develop shale gas extraction. In most countries, by contrast, in Europe as well as in China, below-ground mineral rights are owned by the state.

Global water scarcity and connections to the energy sector – understanding the wider context of water use for shale gas fracking

The demand for fresh water resources is increasing. Water is key to virtually everything connected to human wellbeing, growth and development and sustaining well-functioning eco-systems. Rapid population

Figure 2. Global physical and economic surface water scarcity



Source: Comprehensive Assessment of Water Management in Agriculture (2007, map 2, p. 11). © IWMI, used under licence.

growth, urbanisation and economic growth are major factors that increase this demand.

Agriculture and food production, drinking water supply, energy generation and different industrial sectors are among the areas where water resources are already or are rapidly becoming a limiting factor. On top of this climate change, induced by human activities, intensifies the situation with increased variability in precipitation, changed run-off patterns and prolonged drought periods.

Consequently many areas around the world are facing an increasing level of water scarcity, both physical (areas where more than 75 per cent of surface water resources are withdrawn for different purposes) and economic (where surface water might be abundant relative to use but economic means to make efficient use of the resource are lacking) (WWAP, 2014). In parallel, groundwater resources are also under pressure and are dwindling in some regions. The global footprint of groundwater use is estimated at *3.5* times the size of the actual area of aquifers currently in use, leaving an estimated 1.7 billion people living in areas where groundwater resources and/or groundwater-dependent ecosystems are under threat (Gleeson *et al.*, 2012).

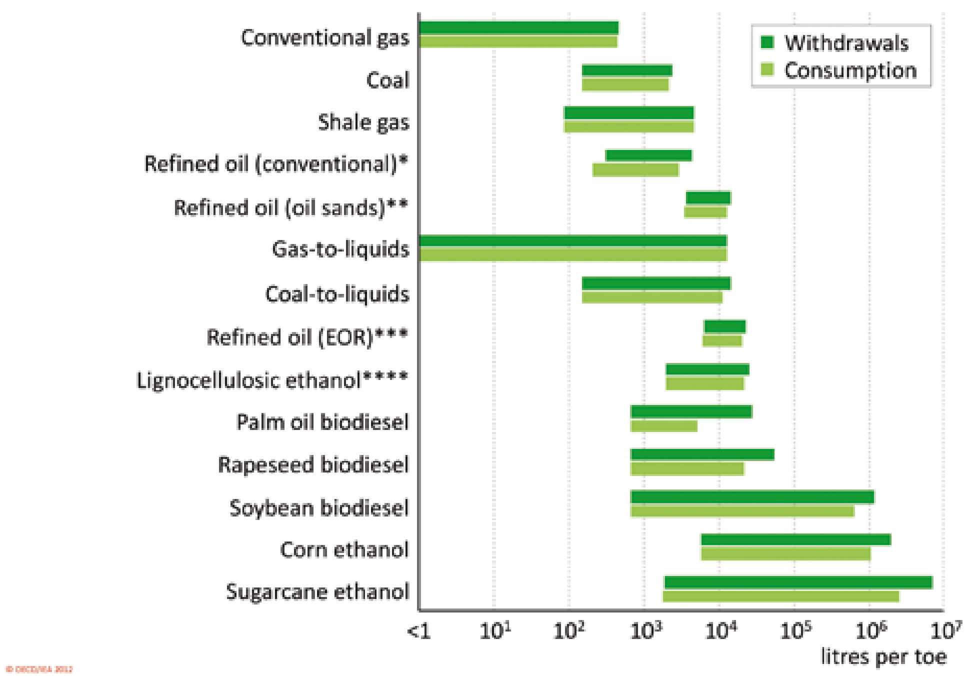
Water use in energy generation

Energy generation is one sector with high water demand. Though agriculture is still the main user of fresh water resources globally, patterns are changing. In mature economies such as the EU and the US, water for energy generation is quickly becoming a dominating part of total water use.

Water is used in all steps of the energy production chain, from fuel extraction and refining to the generation of secondary energy forms such as electric power. Water use in the energy sector is characterized by great variations depending on energy type and the different extraction and generation methods used.

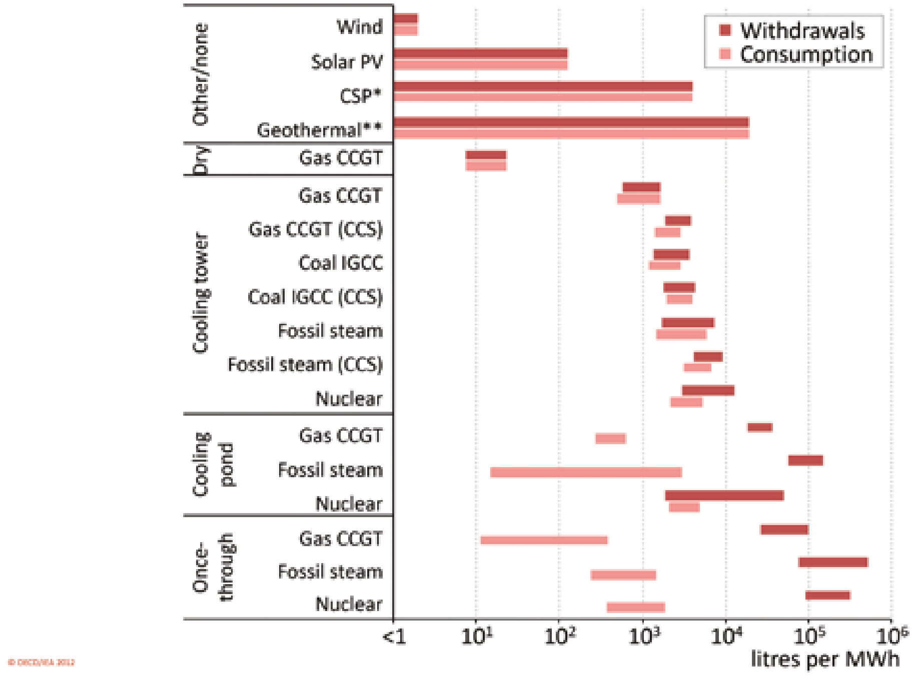
Water withdrawal/consumption ranges for different energy types are illustrated below and on opposite page.

Figure 3. Water withdrawals and consumption for fuel production



Source: IEA (2012a, fig. 17.3, p. 507, based on sources cited therein). World Energy Outlook 2012 © OECD/IEA.

Figure 4. Water use for electricity generation by cooling technology



Source: IEA (2012a, fig. 17.4, p. 510, from sources cited therein). World Energy Outlook 2012 © OECD/IEA.

Biofuels and hydropower reflect different features of water demand. Biofuels, often produced as part of rain-fed and irrigated agricultural systems, stand out because of their high water consumption rates, often being on average 100 times more water-intensive than other fuel. Continued conversions of biofuels to useful liquid or gaseous forms are also thirsty processes.

Hydropower on the other hand is noteworthy because of the variability of its water demand. Highly defined by site specifics and the presence or absence of a reservoir (where water losses occur mainly as evaporation) connected to the production site, hydropower can be among the least water-intensive energy production types (high withdrawal, low consumption) or among the most types (Granit & Lindström, 2011).

Distinctions can also be made on the basis of how water is used: whether it is consumed, or withdrawn and then returned to source. For example, when petroleum is refined water is consumed and contaminated and so cannot be used for other purposes. Generating electricity in thermal power plants requires the cooling of thermal exhausts, but much of the water withdrawn for this can be returned to the source, albeit at a slightly higher temperature, and consumption can be much less than withdrawal. A typical thermal power plant (coal) of 700 MW supplied with a once-through cooling system has a water circulation rate of more than 20 m^3/second (Bathia, 2008). As a comparison Bailonggang Wastewater Treatment Plant, Shanghai, the largest treatment plant in Asia, has a capacity of 23 m^3/s, while Stickney Water Reclamation Plant, Chicago, the world's largest, has a capacity of 63 m^3/second.

Hydraulic Fracturing

History

Artificially stimulating the flow of hydrocarbons from a well is not new. The earliest attempts to do so in the US date back to the 1860s, and involved lowering explosive charges down the boreholes of oil wells. The first experiments with hydraulic fracturing, the coupling of traditional vertical drilling with horisontal boring, took place in 1947. By 1949 the first commercial applications of the technique had been carried out for oil exploration in Texas and Oklahoma by Halliburton. In the 1990s, when hydraulic fracking was tested in the Barnett Shale area in Texas, the "issue was not if you can hydraulically fracture and drill wells in the Barnett, it was if you can do it economically and make money" (Zuckerman, 2013, p. 74). As of 2012, 2.5 million hydraulic fracturing operations had been performed on oil and gas wells worldwide, more than one million of them in the US.

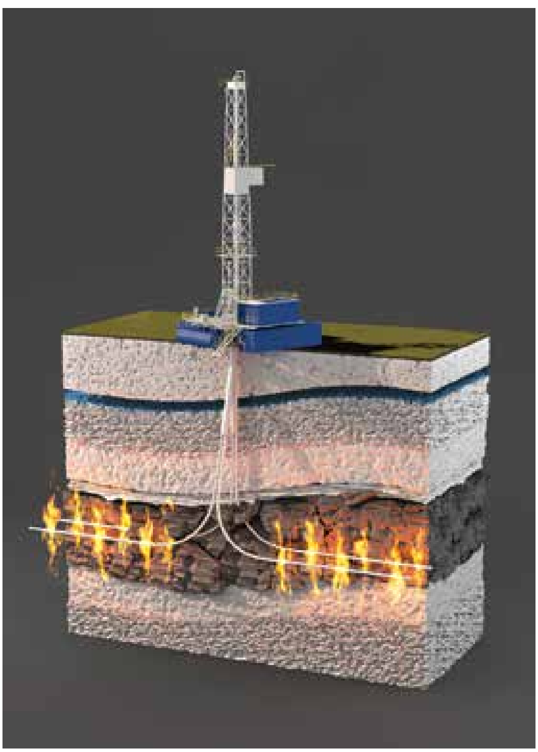


Photo: iStock

Technology

Fracking is used once the vertical drilling is done and the rig and derrick are removed. It involves widening and extending existing cracks in the shale deposit by pumping water mixed with proppants (mostly sand) and chemicals under high pressure, and has been an established part of conventional (vertical) drilling for oil and gas for a long time. Its applications include not only oil and gas drilling but also stimulating flows from water wells, increasing production from geothermal wells, and helping to clean up polluted sites. What is new is the combination of vertical with horisontal drilling, where the drill at depth can be turned 90 degrees to access horizontal shale layers where large amounts of natural gas and oil which are usually trapped can be released by shattering the shale. This technique was unusual until the 1980s when operators in Texas began completing thousands of horizontal wells drilled at the bottom of conventional vertically-drilled wells. The first horisontal well was drilled in the Barnett Shale in north Texas in 1991 and the technique was then applied more effectively in 1997 by George Mitchell, often referred to as the "father of fracking" (Zuckerman, 2013). Some major advantages of horisontal drilling are that wells beneath areas not suitable for drilling can now be reached from a distance, and the "payment zone" (the area from which a borehole can capture released gas) can be increased if the well is "turned" – i.e., horisontal wells into the shale layer can be created in a radial pattern from the borehole.

Incentives for fracking – reason for boom

The only thing that is unique about natural gas released by fracking is the huge amount of it that is potentially available. Natural gas resources that were known about but considered unreachable suddenly became available for commercial purposes, creating what can accurately be called "a new natural gas era". With the addition of fracking gas to the market, costs for residential, commercial and industrial customers have come down significantly.

Spot prices in the US had reached $12/million Btu (or $41/MWh) before dropping to $3-4 ($10-13.5/MWh) more recently, and US prices are expected to increase to no more than $6/million Btu ($20/MWh) in the next decade and $7-8/million Btu (or $23-27/MWh) by 2035 ("Where Are Natural Gas Prices Headed?", Energybiz, February 14, 2014). This, together with concerns for reducing carbon emissions into the atmosphere, has led utilities to substitute natural gas for coal, especially when constructing new power plants. Reduced natural gas costs are also attracting natural gas-dependent industries back to the US from overseas, and are turning it into a probable exporter rather than importer of LNG (liquefied natural gas). Compressed natural gas (gas stored under high pressure in a gaseous state) can also be used directly as a transport fuel and as a starter chemical for alternative liquid fuels, thus reducing US dependence on imported oil. These all have positive implications for the US, for environmental protection, job creation and general economic activity.

On a global basis shale gas, being an indigenous energy resource, can provide lower energy costs, enhanced national security, and job creation in many countries at present dependent on imports for their energy supplies. This has important implications for regions with high natural gas costs (Europe, and even more so Asia) and with heavy dependence on countries where geopolitics can play a major role in determining access to their resources.

Water and the Fracking Process

Despite the huge economic driving forces the environmental consequences of shale oil and gas abstraction by hydraulic fracturing for air and water quality are intensely debated. Water availability will also be strongly influenced by fracking in areas experiencing water scarcity.

After the vertical and subsequent horizontal drilling have been completed and the casings are in place, the casing in the horizontal leg of the wellbore is perforated. Pressurised fracturing fluid is injected into the wellbore and through the perforations to crack the shale rock and release the gas. This fracking fluid can be injected at various pressures and reach up to 100 MPa (1000 bar) with flow rates of up to 265 litres/second. The cracks produced extend 50 to 100 m from the horisontal wellbore and are typically less than 1 mm wide.

The fracking fluid contains around 20 per cent sand and this helps to open and keep open the tiny cracks, allowing gas to flow into the well. The fluid flows back up the well, clearing the way for the oil and gas to be extracted. It also contains pollutants such as benzene which may escape into the atmosphere.

The fracking fluid

Fracturing fluid consists of about 98-99.5 per cent water and proppant. The rest (0.5–2 per cent by volume) is composed of a blend of chemicals, often proprietary, that enhance the fluid's properties (Clark *et al.*, 2012). The concentration varies depending on the geology and other water characteristics. These chemicals typically include acids to "clean" the shale to improve gas flow, biocides to prevent organisms from growing and clogging the shale fractures, corrosion and scale inhibitors to protect the integrity of the well, gels or gums that add viscosity to the fluid and suspend the proppant, and friction reducers that enhance flow and improve the ability of the fluid to infiltrate and carry the proppant into small fractures in the shale.

Water pricing

Fresh water is generally taken from local lakes, rivers and streams, usually free of charge to the gas producers, though some do pay local entities a low rate for some of the water they consume. The water tariffs most often do not reflect the true value of the water. For example, in the Barnett Shale in Texas, drillers paid 0.06 cents/m^3 (0.00022 cents per gallon) in 2009. Major Texas aquifers are running low on fresh water (FracDallas, 2014). Major American cities are running out of fresh water. Fort Worth, close to the Texas shale gas region, is number six on the top ten list of water-scarce cities. Water is also subsidised for farmers, for example in water-scarce areas like California's Central Valley and in the Midwest. As a result many groundwater sources have been over-extracted.

Different Aspects of Water-Related Risks from Fracking

Water availability

The two primary water issues associated with fracking are: the use of a large amount of fresh water that becomes contaminated and which can never again be used by humans, animals or plants for any purpose unless treated; and the need to protect underground water tables and surface water from contamination by fracking fluids and/or migrating gas flows.

Water availability is crucial for fracking. Often the shale gas is found in dry areas. Although overall water use for shale gas and hydraulic fracturing is low in comparison to other users (such as cooling water for thermal power plants), in some water-scarce areas it constitutes a large demand on groundwater resources and could lead to potential water shortage.

Water is also needed for the drilling operation itself, before any hydraulic fracturing can take place; this is typically less than 10 per cent of the total requirement. Typical water requirement varies from 250 m^3 per well (Fayetteville Shale, Arkansas, US) to around 2,300-4,000 m^3 (Haynesville shale). The amount of water depends on the types of drilling fluids used and the depth and horisontal extent of the wells (Clark *et al.*, 2012; EPA, 2012). The industry claims that many gas wells have a useful production life of 20-40 years, and must be re-fractured every 3-5 years in order to maintain an economically viable production flow. That indicates that the total volume of fresh water usage during the lifetime of a well is several times the volume required for one fracking operation. Thus the total water requirement for a well during its entire lifetime can be anywhere between 24,000 m^3 and 500,000 m^3. The US Environmental Protection Agency (EPA, 2012) estimates that about 11,000 new wells are hydraulically fractured every year in the US. The rapid decrease in the productivity of individual wells over time requires drilling new wells to maintain current production.

For example, in the Eagle Ford Shale of West Texas rainfall is rare. Texas is facing the worst drought in recorded history, and aquifers in West Texas are dangerously low – in some cases having less than 30 days' supply of fresh water. Without additional rainfall local residents will be forced to buy and truck in water from outside sources. Three years of drought, decades of over-use and now the oil industry's demands on water for fracking are running down reservoirs and underground aquifers. And climate change is making things worse. According to the Texas Commission on Environmental Quality, about 30 communities in the state are running out of water. Some farmers and landowners have tried to make money from water by selling groundwater to the oil industry, causing aquifers to run dry. For example, a land owner in Texas earned some $60 per truck load and could sell 20-30 truckloads every day (FracDallas, 2014). He made a lot of short-term money but was left with a dry well, and the land could no longer produce any food or supply the area with water. In adjacent

Crockett County, fracking accounts for up to 25 per cent of water use, according to the Groundwater Conservation District.

Producers like to claim that the amount of water they use is small compared to that of other users, but most water used by cities, industry, agriculture, etc. is recoverable and treatable for reuse, whereas fracking water generally cannot ever be used again except for fracking purposes, unless it is treated at considerable cost.

In China the great obstacle to fracking is water availability. China has among the largest shale gas reserves in the world (see Figure 1) as well as the world's third largest reserves of shale oil. The gas is found in dry regions of the country (particularly in the west). Additionally the Chinese shale seems to require more water to frack than the US formations, and most of China's gas is found in mountainous regions that are prone to earthquakes and at great depths.

Mexico suffered a severe drought in 2012 and does not seem to have sufficient water supplies to expand its fracking efforts. The south-east of England, an area the fracking industry is particularly interested in, already has water supply problems and was in drought recently. Mexico and the UK have suffered extreme weather with both droughts and floods. Water scarcity is also a critical issue in South Africa, where large shale gas deposits have been found in the Karoo desert. This has led to much opposition by environmental groups (e.g. WWF-SA) to the proposed fracking.

The Risk Matrix by Resources for the Future (RFF)

Much effort is going into identifying and describing fracking risks and their potential or already-observed impacts. One useful source of information is the Risk Matrix being developed by Resources for the Future (RFF), which divides shale gas development into six broad categories based on input from more than 200 shale gas experts in industry, academia, and government agencies: site development and drilling preparation; drilling activities; fracturing and completion; well operation and production; fracturing fluids, flowback, and produced water storage and disposal; and "other" activities:

- Site development and drilling preparation involves clearing of land, construction of roads, well pads and other infrastructure, and on- and off-road vehicle activity;
- Drilling activities include those at the surface and in the wellbore, casing and cementing of the well, use of surface and groundwater, venting of methane, surface storage of drilling fluids, storage and disposal of wastewater fluids, and associated vehicle activities;
- Fracturing and completion involves further use of surface and groundwater, perforation of the casing at fracking depth(s), horisontal drilling, high pressure fracking and introduction of proppants into the horisontal wells, flushing of the wellbore, flowback of well fluids, and venting and flaring of uncaptured methane;
- Well operation and production requires use of compressors and dehydration equipment;
- Facturing fluids, flowback, and produced water storage and disposal involves on-site pond and tank storage, on-site and/or off-site treatment and re-use, deep underground injection, and vehicle activities; produced water is defined as the water that is brought to the surface during the production of oil and gas. It typically consists of water already existing in the formation, but may be mixed with fracturing fluid if hydraulic fracturing was used to stimulate the well.
- Other activities include shutting-in of operating wells (i.e., implementing a production cap lower than a well's capacity), and plugging and abandonment of depleted wells.

Information compiled from: Krupnick, A., Gordon, H., and Olmstead, S. (2013). Pathways to Dialogue What the Experts Say about the Environmental Risks of Shale Gas Development. Resources for the Future: Washington DC.

Groundwater contamination

A lot of attention has been directed toward the possibility of subsurface migration of fracturing fluids or hydrocarbons into groundwater aquifers. Low-permeability natural gas resources are in geological formations located at depths of 450-4,500 m below the surface, with natural gas wells averaging 2,000 m (Clark *et al.*, 2012). At these depths, the formations usually underlie drinking water aquifers, which are commonly 30-100 m below the surface. The fact that fracking wells pass through aquifers is a major concern. This puts a stringent requirement on the integrity of the well's casing and surrounding cement to protect against leakage and contamination.

Several different pathways for migration have been proposed but the risks vary (NETL, 2013). One potential pathway is through the casing/wellbore ring like structure when there is poorly cemented casing around the wellbore as it passes through and beneath potable water aquifers (Vengosh *et al.*, 2013). In this situation, the drilling of new shale wells could connect deeper natural gas bearing formations with shallower aquifers, and in the presence of sufficient pressure differential, cause natural gas to reach the water zone.

Another potential pathway is a situation where the drilling of the shallow section of a new shale gas well temporarily permits communication between shallow gas-bearing zones and water supply aquifers. Pressure differentials under these circumstances could potentially cause gas communication.

Another pathway could be through poorly cemented wellbores from long-abandoned "orphan" wells. Higher pressure gas from deeper formations could potentially find a path behind poorly cemented casing to a shallower, lower pressure zone of past production, which in turn communicates with an even shallower aquifer via the abandoned wellbore.

Several recent studies have attempted to find incontrovertible evidence of a connection between hydraulic fracturing and shallow water zone contamination, without success. A number of ongoing studies are continuing to assess this risk. (NETL, 2013).

Flowback (returned) water, in addition to fracking chemicals, can also contain brine, heavy metals and radioactive contaminants in addition to the methane that is released. It is with the often expensive handling of this flowback that many people are concerned. It is a point in the fracking cycle where extraction companies may be tempted to take shortcuts to reduce costs. If properly treated, returned water can be reused in other fracking operations. But treatment methods for the returned water are usually inadequate to achieve any drinking water standard. If improved treatment procedures are developed, it will most likely be at considerable cost.

There have been several mishaps with hydraulic fracturing affecting groundwater aquifers. Often the regulations have been far from strict and not strongly enforced by the regulators (Gruver, 2011). As long as there is not a transparent and strongly regulated operation it is difficult to minimise or remove all the risks.

The leakage potential is also a serious concern because water supplies can be contaminated by exposure to methane which is a powerful climate change gas, many times more potent at trapping heat than carbon dioxide. Fortunately, methane stays in the atmosphere for a much shorter time than CO_2. The leakage can arise in several ways – leakage to the surface through natural underground fractures outside the wellbore, leakage through poorly constructed well casings and the cement barriers around the casings, and leakage at the surface from leaky infrastructure and pipelines. These sources of leakage are some of the industry's greatest concerns.

Another major concern, possibly associated with the disposal of fracking wastewater in deep injection wells, a common practice, is the possibility of triggering small earthquakes. (Ellsworth, William L., "Injection-Induced Earthquakes", Science, July 12, 2013). This arises from the lubricating effect of the pressurised injected water on underground geological faults. According to the US Geological Survey (USGS) such injection "...has been linked to a six-fold jump in quakes in the central US from 2000 to 2011." More recently, Ohio has implemented new regulations on fracking after seismologists determined that the epicentre of a 3.0 magnitude earthquake in early March was directly under wells being fractured in Poland Township. The new regulations will require companies seeking horisontal well drilling permits within three miles (5 km) of known fault lines or where quakes have already been recorded to first install a network of seismic detectors. If the monitors detect a seismic event of magnitude 1.0 or greater the fracking will be paused and indefinitely suspended unless the quake is determined to be in the bedrock below the fracturing.

Oklahoma has also experienced significant increases in seismic activity which some scientists say is linked to fracking operations in the state. Six earthquakes, ranging in magnitude from 2.6 to 3.8, were recorded in a two-day period in early April 2014. According to the Oklahoma Geological Survey "..not even four months into 2014 the state has already experienced more earthquakes (252) than it did the entirety of 2013 – itself a record-breaking year with 222 quakes recorded."

As a result of this increased seismic activity in the mid US, and despite denials of a possible linkage between fracking and earthquakes by the American Petroleum Association ('Shale Energy: 10 Points Everyone Should Know', API, October 2013), state officials from Oklahoma, Ohio, Texas and Kansas have recently initiated efforts to coordinate and strengthen regulations and permitting standards for fracking operations.

Another category of risk not included above is potential accidents. Spillage of fracking fluids or wastewater during routine operations or during storms can jeopardize nearby surface and groundwater supplies. Another risk, well known in the oil and gas industries, is the blowout of a well and subsequent fire, as is reported to have occurred recently in Jiaoshizhen, China (New York Times, April 11, 2014).

Finally, fracking is today a poorly regulated industry in the US, where it is well under way. In June 2014 the US Environmental Protection Agency reported that 4 in 10 new oil and gas wells near national forests and fragile watersheds, or otherwise identified as higher pollution risks, escape federal inspection. The agency struggles to keep pace with the drilling boom. The shale gas industry is exempt from seven major federal regulations, including the Clean Water Act, the Safe Drinking Water Act, and the Superfund law which requires that polluters remediate for carcinogens like benzene unless they come from oil and gas production. Corporations are exempt from revealing the chemicals used in fracking fluid, the so-called Halliburton Loophole, although some voluntary disclosure is now taking place. The Resource Conservation and Recovery Act also exempts fracking from regulations relating to hazardous waste.

Produced water

Wells in the Marcellus, a large shale gas deposit extending throughout much of the Appalachian Basin in the eastern US, generate on average 5,200 m^3 of wastewater (12 per cent drilling fluids, 32 per cent flowback; 55 per cent brine). Typically the salinity in the Marcellus brine is around 250 g/L, 10 times that of seawater (Lutz *et al.*, 2013). Of the water that goes down the well bore as a medium for the fracking, a significant fraction comes back out of the wells as wastewater (including drilling muds, flowback water and produced water that is released from underground sources). The volume of produced water that is returned varies greatly, depending on the geological characteristics of the formation; it can be as low as 15 per cent and as high as 300 per cent.

The "recovered" water that does come back up is stored in tanks or often in lined or unlined aboveground pits until it can be pumped into tanker trucks and hauled off for deep well injection far below the earth's surface. Some of the flowback water spills on to the ground around well pads where it contaminates the local area and possibly produces adverse health effects for rig workers and the neighbouring community. Many cases have been documented where tankers leaked, where valves were accidentally or intentionally opened allowing the produced water to flow out on to roadways and roadsides, where traffic accidents resulted in massive spills, or where the water was illegally dumped on to private or public land or into rivers, lakes or streams rather than being pumped into injection wells, as claimed by drilling operators.

Threats to surface waters

The development of any gas well creates surface disturbances as a result of land clearing, infrastructure development and the release of contaminants produced from the drilling and fracturing operations. Contamination from fracking-fluid chemicals adds extra threats. Reductions in water levels, contamination of streams from accidental spills, and inadequate treatment practices are realistic threats. More scientific measurements and documentation are needed that will inform decision-making and ensure protection of water resources.

Gas wells are often sited close to streams, increasing the probability of harm to surface waters. (Entrekin *et al.* 2011) have used geographic information system tools to generate detailed drainage-area networks in shale reservoirs where gas wells occur at high densities. As the densities increase, the proximity of wells to stream channels may also increase. This may result in a greater risk of water reduction as a result of pumping as well as contamination from leaks and spills from the fracking operations. Onsite waste ponds could overflow, spill or leach into groundwater and into streams close to the site. The wastewater contains high concentrations of total dissolved solids (TDS), from around 5,000 to more than 100,000 mg /L. Common municipal treatment plants are either unable to treat this water, or have to limit their intake of recovered wastewater from the fracking operations.

Other Threats Linked to Shale Gas and Fracking

Air quality

Any oil and gas drilling operation impacts air quality. Dust and engine exhaust from truck traffic and emissions from diesel-powered pumps are health hazards. These emissions include primarily ozone precursors like NOx and non-methane volatile organic compounds (VOC), and particulates. In some cases extremely high ozone levels have been reported, comparable to major cities in their worst conditions (Gruver, 2011).

Air quality is also influenced by methane emissions during the well completion process when wells are flowed back or tested. This can include emissions from flares used to burn off excess natural gas. Still another source of air pollution is non-combustion particulates, both from gravel roads constructed for drill pad access as well as from silica dust from proppant handling during hydraulic fracturing. The silica sand can lodge in lungs and cause silicosis.

Equipment used during the gas and liquids production process can also create harmful emissions, including inadvertent methane releases from valves, compressor blowdown, and VOCs such as BTEX (Benzene, Toluene, Ethylbenzene and Xylenes) that escape from condensate or oil tanks. Several studies are under way (NETL, 2013) to attempt to quantify the individual as well as cumulative impacts.

Greenhouse gas emissions and climate change

In a balanced energy generation scenario shale gas will tend to displace the use of coal as it has done in the US. Natural gas has less than half the carbon footprint of coal and emits only about two-thirds as much CO_2 as oil when combusted. Therefore it has been seen as a more favourable energy source. The truth of the matter is, however, that it still remains a fossil fuel and releases CO_2 when burned.

Extraction of gas from shale formations may eventually also produce significantly more methane than conventional wells and could have a larger carbon footprint than other fossil fuel development due to uncontrolled leakage (Howarth *et al.*, 2011).

The relative contribution to climate change of natural gas as an energy source compared to other options (e.g. coal) has been calculated through life cycle systems analyses. Because methane is a more potent greenhouse gas than CO_2, methane emissions during natural gas production and transport can offset the CO_2 saving of gas over coal.

A number of studies are under way to more accurately characterise exactly how much methane is lost across the entire natural gas value chain (NETL, 2013).

Measurements reported in 2013 at 190 natural gas production sites across the US found that the majority of hydraulically fractured well completions had equipment in place that reduces methane emissions by 99 per cent compared to earlier operations (UTexas, 2013).

Health and social issues

There has long been speculation that fracking can pose risks to human health and the environment when additives included in the fracking fluid leak into the surrounding environment. Reports are emerging from locations close to fracking sites of people being affected and falling ill from contaminated water or air contact with fracking chemicals. Particularly in the US have suspicions surfaced of potential effects which might have many explanations. From having been an activity mostly carried out in sparsely populated areas, fracking now has a substantial presence in more densely populated areas such as upstate New York and Pennsylvania, which of course increases the chances of contact with people. Fracking is also a comparatively deregulated activity in the US, increasing the risks of unsafe practices linked to extracting shale gas.

It is in the US that much science and research has been conducted to try to establish facts about possible risks. Though there seems to be some circumstantial evidence pointing to both humans and livestock falling ill in areas close to fracking sites, with local spikes in people seeking health care for symptoms that can be caused by exposure to fracking chemicals, indisputable scientific support for this is yet to be produced. Reasons for science lagging behind are partially explained by the secrecy surrounding the proppants and other additives that companies are using: they can be considered "trade secrets" under current legislation.

However there is an increasing number of scientific studies that provide systematic evidence which supports suspicions of the possible health dangers of fracking. The US House of Representatives Committee on Energy and Commerce released a list of fracking chemicals in 2011, many of which are considered toxins, including xylene, naphthalene, methanol, formaldehyde, ethylene glycol, hydrochloric acid, sodium hydroxide, benzene, ethyl benzene, toluene and many others. Some of the chemicals named in the report have also been identified as endocrine disruptors (affecting the endocrine system), able to block hormones and disrupting bodily functions. Recent work by the University of Missouri involving testing known fracking chemicals identified as endocrine disruptors, as well as collecting ground and surface water samples from known fracking sites, yielded many telling results (Kassotis, 2013). Among twelve tested chemicals the researchers found that an overwhelming majority were in fact hormone-disrupting and higher than average endocrine disrupting activities could be detected in water samples collected from drilling sites compared to low activities in samples taken from sites not associated with fracking activities (ibid.).

There has also been scientific support to support fears that methane is leaking to surrounding water sources. While lesser concentrations of methane in drinking water are not considered immediate health hazards they can be highly flammable and can pose fire and explosion risks. A study by Duke University and published in the Proceedings of the National Academy of Sciences in 2011 found that methane and ethane concentrations were several times higher in residences closer to fracking sites than among 141 other sampled sites in Pennsylvania (Osborn, 2011). However the study noted difficulties in proving, without doubt, that they could actually be linked to fracking activities rather than simply being naturally occurring methane.

There are varied social implications linked to natural gas extraction both positive and negative.

The immediate benefits of increased gas production in shale gas regions – such as jobs, higher income levels, lower prices for electricity and gas, and tax revenues – can be measured relatively easily (Adgate, 2014).

The negative impacts may be harder to quantify but they are also noticeable, not least in communities directly linked to drilling sites, and they often concern already vulnerable groups.

Among the less attractive impacts are rapid and unplanned industrialisation. Municipal services can be strained and stress levels and quality of life adversely affected. The impacts of rapid growth in shale gas exploration play out differently in different communities, depending on population density, growth rate and available funding for mitigating impacts. Rapid population increases as a result of industry and workers moving into communities have seen housing rental prices go up, making it difficult for people with smaller incomes to compete. The drilling and fracking operations have resulted in many quiet rural areas being turned into noisy and polluted neighbourhoods. Drilling is an industrial activity that brings intense noise, traffic and disturbance to residents near active wells. The roar from diesel generators and the pumping of fracking fluid into a well 2-3 km below the surface is naturally disturbing. Since fracking often takes place in dry areas the trucking in and out of water causes extra traffic and considerable dust.

The fluid returning to the surface creates disputes. Until 2008 drilling and fracking in the US had not stirred a lot of controversy. Much of the fracking was in sparsely populated areas or in states like Texas, where the support of the energy industry has traditionally been strong.

Many residents close to the fracking operations have seen their property values decrease. In some cases gas production facilities nearby also received tax appraisals that were lower than in previous years because their own activities reduced the market value of their properties (FracDallas, 2014).

The substantial value of lost ecosystem services, not least recreation and tourism, are also losses that can be tied to the fracking industry but are difficult to monetise (Adgate, 2014).

Photo: iStock

Case Descriptions

Europe (outside Russia)

Europe is rich in shale gas reserves. According to recent estimates made in the EIA/ARI Study, Europe's technically recoverable shale gas reserves amount to $25{\cdot}10^{12}\ m^3$ (883 Tcf), (EIA, 2012, Table 2A). The development of shale gas in Europe can help diversify its gas supply sources, and help it to move away from its current heavy dependence on Russian gas. This dependence is viewed differently in different European countries. Poland has issued 101 exploration permits to 25 companies, while Hungary has refused to explore its shale basin because of water contamination fears.

Norway's shale gas assessment dropped from $2.4{\cdot}10^{12}\ m^3$ (83 Tcf) in 2011 to zero in 2013 (EIA, 2013) because of the disappointing results obtained from three Alum Shale wells drilled by Shell in 2011.

Poland and the Baltic states wish to become energy-independent of Russia, the more so given recent developments in Ukraine. Although Poland has always been apprehensive about its dependence on Russian gas, it has issued nearly 25 per cent of its shale gas exploration permits to Russian companies (WEC, 2013). With an established onshore conventional oil and gas production industry as well as recent experience with coalbed methane exploration, Poland offers Europe's best prospects for developing a viable shale gas/oil industry (EIA, 2013). Its shale industry is still at an early exploratory, pre-commercial phase. About 30 vertical exploration wells and a half-dozen vertical and two horisontal production test wells have been drilled to date. However, early results have not met the industry's high initial expectations.

In the UK, indications so far are that the country has enough recoverable shale gas to completely replace its gas imports for more than a century. The Government has claimed (in 2014) that the UK "needs to cut energy costs". The Government will be "investing" in "a shale gas revolution". The Ukraine crisis has added another dimension to the debate. Michael Fallon, the Energy Minister, has stated that "shale gas is important to the UK's energy security of supply. The UK has issued a number of shale gas exploration permits. Russia's dealings with the Ukraine have exacerbated this." (BBC News, May 23, 2014).

Despite this, shale exploration in the UK has not yet taken off as it has in the US There are many suggested reasons for this sharp contrast. Investment in the UK has so far been modest. In early 2014 it was estimated that only some £100 million is being spent on shale gas exploration there. This contrasts with the £2 billion a year subsidies for renewable electricity in the UK.

Probably the main reason why activity has been restrained so far is resistance from local populations and policymakers. People are afraid that fracking will destroy the landscape, pollute drinking water aquifers and cause earthquakes.

Another strong reason is the existence of stricter environmental legislation, preventing or slowing rapid shale gas development as in the US. The intense environmental debate over fracking in the US has been observed by European nations and has induced different responses among the continent's governments (KPMG, 2011). In countries such as France, Bulgaria and Germany fracking is effectively banned (Wall Street Journal, 2014). In countries where fracking is allowed such as Poland, Ukraine and the United Kingdom, other issues have played a part in halting rapid development. Effective environmental lobbies and laws have played their part in slowing growth. Technical issues have also been involved, mainly due to the geological differences between Europe and the US (BBC, 2014). Consequently it can be argued that Europe is unlikely to experience a shale gas revolution at the scale that has been seen in the US.

Though development in Europe has not been rolled out with the same intensity as in the US, and European governments' positions tend to be more hesitant, it would be wrong to conclude that shale gas exploration will not eventually pick up pace. Geopolitical, climate and economic reasons could be potential motivators.

In parallel the role of shale gas can also be viewed in a European context of existing strategies to move away from CO_2-emitting fossil fuels while striving to increase renewable energy in the energy mix. An expansion of shale gas could also mean substantial cuts in energy prices and new job opportunities. There are some signs to suggest that the EU might be paving the way for increased deployment of shale gas. In a March 2014 vote, the European Parliament adopted a new law imposing stricter rules on assessing and disclosing the environmental impact of oil and conventional gas exploration. However this could only be done if exemption was made for shale gas (deemed as an "upstream" energy source), largely attributed to effective lobbying from Poland and the UK (Reuters, 2014).

North America

The development of shale gas extraction has started in the US while other countries are still on the starting blocks. Huge oil and natural gas resources have given North America hopes of becoming what some call "Saudi America".

Mexico also has huge resources of oil and gas. Energy operations and supply have been tied to the US ever since the late 1970s, when Mexico discovered great riches offshore. During the past decade Mexican production has dropped. Oil exports to the US declined from 1.7 million barrels a day (b/d) in 2006 to 1 mn in 2014. In 2013 it was estimated that Mexico may have 29 billion barrels of oil and gas reserves in the Gulf of Mexico, and an additional 13 billion barrels of recoverable oil shale reserves. Production could increase by 25 per cent by 2024 to nearly 4 mn b/d, potentially vaulting Mexico to fifth or sixth position among the biggest oil producers.

The problem for Mexico is that the national oil company Petróleos Mexicanos has had a monopoly on production and gasoline sales since the 1930s. The country is pressing ahead with constitutional changes and the promise to open exploration and production to international oil companies for the first time since the 1930s, but still investors remain cautious.

Canada has become a big energy player. Only a decade ago Canada's oil sands were no more than an afterthought in the energy world. Oil prices were just beginning to increase enough to make mining in sub-Arctic northern Alberta economically viable. The Canadian oil sands represent one of the world's top three oil reserves, after Venezuela's and Saudi Arabia's. The biggest oil find in the world in 2013 occurred off the coast of Newfoundland.

The US Situation

Fracking has now been used in more than one million producing wells in the US over the past six decades. Its use has proliferated in the past five years after years of steady decline in domestic oil and gas production as reservoirs of conventional sources dried up. The adoption of horisontal drilling as an adjunct to vertical drilling has enabled the US to enter a new natural gas era, and operators now fracture as many as 35,000 wells of all types each year. Shale gas, sometimes labelled unconventional gas, accounted for 1% of natural gas supplies in 2000, 30 per cent in 2011, and is projected to increase to 64 per cent in 2020.

While the vast majority of these wells have been operated safely and have created many jobs, a few cases have raised red flags within the industry and among the public. This has led to a vigorous debate about fracking in the US and in a few other countries where fracking is just getting under way or is contemplated.

The US experience includes the story of Dimock, with a population of 1,400, in the Appalachian section of Pennsylvania (PA). It is now known as the town where residents' water started turning brown and making them and their animals sick after shale gas fracking was initiated under their land by Houston-based Cabot Oil & Gas Co. in the late 1990s (underground property rights in PA do not vest with surface property rights). Dimock and other communities in the Delaware River basin are located above a vast rock formation rich in natural gas known as the Marcellus Shale Deposit, which stretches for more than 925 km (575 miles) under parts of West Virginia, Pennsylvania, Ohio and New York. It is one of the largest natural gas fields in the world.

Another Pennsylvania experience was documented in a report about the Hallowich family in Washington County ('Frack Gag' Bans Children from Talking about Fracking, Forever; Breiner, Andrew, Climate Progress, August 2, 2013).

It begins: “When drilling company Range Resources offered the Hallowich family a $750,000 settlement to relocate from their fracking-polluted home in Washington County, PA, it came with a common restriction. Chris and Stephanie Hallowich would be forbidden from ever speaking about fracking or the Marcellus Shale. But one element of the gag order was all new. The Hallowichs’ two young children, ages 7 and 10, would be subject to the same restrictions, banned from speaking about their family’s experience for the rest of their lives”.

“The Hallowich family’s gag order is only the most extreme example of a tactic that critics say effectively silences anyone hurt by fracking. It’s a choice between receiving compensation for damage done to one’s health and property, or publicising the abuses that caused the harm. Virtually no one can forgo compensation, so their stories go untold.”

Stories of Pennsylvania communities like Dimock and others in Colorado, Wyoming, Utah, and Texas, which claim to have been harmed by fracking, were popularized in an American documentary film released in 2012, Gasland. It was followed by Gasland 2 after its conclusions were questioned strongly and even denied by the US oil and gas industry. (Frack-no-Phobia, Hopper, Regina, America’s Natural Gas Alliance, July 27, 2012). Federal and state investigations are under way.

China

Two key persons in China for climate policy and energy have provided a picture of Chinese shale development. They are Professor Ye Qi, director of China’s Climate Policy Institute at Tsinghua University, Beijing, and Ambassador Wu Jianmin, executive vice-(Howarth *et al.*, 2011) chairman of the China Institute for Innovation and Development Strategy. It is emphasized that a switch from coal to gas in China does not necessarily lead to lower CO_2 emissions. One reason is that much of the gas that China uses comes from coal gasification, using coal for example from Inner Mongolia. Shale gas is at quite a rudimentary stage. Production is still low and no real breakthrough is predicted in the near future. Shale gas will probably not start to play a significant role in China before 2030.

The technology being used in the US doesn’t seem to be the most appropriate one for China. The gas is located deeper than in the US and water scarcity in these regions is serious. So the current cost of drilling a shale gas well in China is reported to be several times higher than in the US. But the prediction is that from 2030 onwards shale gas production will quickly pick up and grow fast. For the moment China’s major national oil firms appear to be reluctant to make large R&D investments in domestic shale gas because of the alternative investment choices currently available to them.

Air pollution has become a major driver of climate action because much of it is from burning coal. To reduce this pollution China needs to reduce the use of coal. But using less coal does not necessarily reduce total fossil fuel energy use. Some cities, for example Beijing, have seen a major shift from coal to gas. But gasification is energy- and water-intensive, so actually it takes more coal to generate electricity that way.

Ambassador Wu says air pollution from coal burning is a great risk. By developing gas the smog problem can be limited, and this is considered more important than the environmental problems of shale gas exploitation. Today gas represents only 5 per cent of Chinese energy consumption, and China aims to double this to 10 per cent. The world average is 2.4 per cent. Increased gas consumption can make a significant difference in air quality. To make this possible China firmly intends to develop its shale gas reserves, but the technology to develop them is still lacking. Yet China and other countries new to shale gas enjoy a major advantage over the US in that the state-of-the-art shale gas technologies are much more advanced than those that existed when the Americans started to develop it.

In January 2014 China held $4.4 \cdot 10^{12}\ m^3$ (155 trillion cubic feet, Tcf) of proven natural gas reserves, the largest in the Asia-Pacific region. Its natural gas production more than tripled to $0.1 \cdot 10^{12}\ m^3$ (3.8 Tcf) between 2002 and 2012. It was a net gas exporter until 2007, when it began to be a net natural gas importer. Since then, imports have increased dramatically in tandem with rapidly developing pipeline and gas processing infrastructure. Natural gas imports met 29 per cent of demand in 2012.

Xinjiang is historically one of China's largest and most prolific gas-producing regions, with an output of $23{\cdot}10^9\ m^3$ (827 billion cubic feet, Bcf) in 2012. That year the Tarim Basin in Xinjiang was (Howarth *et al.*, 2011) China's second-largest natural gas area, supplying $19{\cdot}10^9\ m^3$ (680 Bcf) or 18 per cent of China's total production. The Sichuan Basin is China's key gas-producing area in the south-western region. It is anticipated that the major field there, Yuanba, will produce $3.4{\cdot}10^9\ m^3$ (120 Bcf) by 2016.

China is rapidly approving coal-to-gas (CTG) projects as it encounters higher natural gas demand alongside supply shortfalls, and as coal remains an abundant resource. It was set to produce gas from its first CTG plant in 2014. The country is investing 14 billion US$ in four CTG projects that will supply Beijing and other regions with more natural gas by 2015.

Most of China's proven shale gas resources are in the Sichuan and Tarim basins in the southern and western regions and the northern and north-eastern basins.

Resource estimates of other sources are lower, and the Ministry of Land and Resources (MLR) reported total shale gas technical reserves were $25{\cdot}10^{12}\ m^3$ (883 Tcf) in 2012. Shale gas production in 2012 was only $0.05{\cdot}10^9\ m^3$ (1.8 Bcf) from test drilling in the Sichuan basin, falling far short of the Ministry's goal of producing $6.5{\cdot}10^9\ m^3$ (230 Bcf) of shale gas by the end of 2015 and at least $60{\cdot}10^9\ m^3$ (2,100 Bcf) by 2020.

China's potential abundance of oil and gas resources has prompted the Government to seek foreign investors with the technical expertise to exploit them. In particular, the country's national oil companies are in discussion with several international counterparts about partnering on potential shale gas projects in order to gain the necessary technical skills and investment for developing these geologically challenging resources. At the same time, Chinese national oil companies have been actively investing in shale oil and gas plays in North America to gain technical expertise in this arena.


Photo: iStock

Recommendations

As this review documents, shale gas and oil production is well under way in the US and Canada, starting to get under way in China, and is being strongly debated in many other countries. It is a very large fossil fuel resource, of both gas and oil, and brings many advantages to countries with exploitable shale resources – reduced energy costs, job creation, reduced carbon emissions from the burning of natural gas rather than coal for power generation, and increased national security. Unfortunately, it also brings major demands on water supplies, serious risks of possible air and water pollution and the possible triggering of seismic events if not regulated and managed carefully. Fracking operations also have the potential for major community disruption from associated vehicle activity.

Given human nature, our economic system, and the huge financial returns expected from fracking, and in some cases already realised, the authors conclude that, despite the obvious risks, large-scale fracking will occur in many countries. This includes countries which are still hesitant and looking carefully at fracking's pros and cons. A good example is the UK, where currently there is no fracking but a vigorous debate has developed, based on examination of the American experience. The British health agency (Public Health England, PHE) has said in a review that "…any health impacts were likely to be minimal from hydraulic fracturing as long as operations are properly run and regulated..."

These latter words are key, in our opinion. The financial and other benefits of fracking are too great to stop it, despite the risks, and we will have to deal with fracking for many decades ahead. Investments in fracking are also likely to delay needed global investments in clean energy (efficiency and renewables). Careful understanding of the full spectrum of risks, and strict regulation of fracking at national, regional and local levels will be required. Given the costs involved in ameliorating risks we can expect some attempted shortcuts by extraction companies (especially smaller companies with limited financial resources), and occasional accidents. However, this is true of other energy sources as well and is an inevitable part of supplying energy needs. It will be society's job to create disincentives for these shortcuts, to educate the public about the risks and tradeoffs, and to keep the pressure on the extraction companies and government officials to adhere to and enforce the regulations.

With this context in mind the authors make the following specific recommendations to government/regulatory decision-makers:

1. Central and/or local governments engaged in or contemplating shale gas extraction must have clearly defined policies and enforcement strategies in place if the adverse consequences of fracking are to be minimised or avoided.

This requires the development and use of a check list that covers both the anticipated benefits of fracking (market value of the shale gas and its jobs and other positive economic impacts) and areas where poor practices and inadequate regulation can lead to negative impacts such as:

a. increased water demand
b. inadequate treatment of returned water
c. improper disposal of waste water
d. possible triggering of seismic events
e. community and social disruption due to operational activities.

This check list should be based on the best available science and informed by best practices elsewhere. Regulations must be broadly implemented and adopted in a transparent, participatory process that allows all stakeholder voices to be heard.

Where conflicts arise between broad public interests and the protection of proprietary information, enforcement agencies must insist on full disclosure to ensure maximum protection of public health and the environment, including disclosure of underground mining rights that may not belong to individual property owners.

2. The current research gap on possible negative impacts related to fracking must be closed as quickly as possible, to facilitate informed decisions.
These impacts include damage to water and air quality, global warming consequences from fracking operations, seismic damage from injected water, and community disruption.

Impacts research should also include analysis of the positive benefits of fracking and the costs of compliance. Research on improved fracking technologies and treatment of waste water returns needs to be encouraged and supported.
3. Water quantity and quality impacts must be fully reported, monitored and regulated.

There must be full disclosure of fracking water sources, quantity and costs, monitoring and disclosure of waste water quality and disposal, a requirement for mining permits for the use of fossil (ancient, non-rechargeable) water, and identification of competing water uses.

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Shale Gas and Hydraulic Fracturing
Framing the Water Issue

The emergence of shale gas is quickly changing the energy landscape. Its extraction method, hydraulic fracturing, is a hotly debated issue due to its potential environmental implications.

This SIWI report presents the most recent research in the field and critically assesses hydraulic fracturing and its impact on freshwater resources.

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