

**Energy
Essentials**

A guide to shale gas





Introduction

Energy is a topic of enormous and growing interest to both government and the public. We face difficult choices about security of supply, affordability, and the environment. Since 2008, the 'shale gas boom' in North America has brought this particular unconventional gas, and the techniques used to produce it, to the forefront of the energy debate. Recent resource assessments have stimulated interest in the prospect for shale gas development in the UK. There has been a vigorous debate about the potential benefits and risks of developing this resource. Perspectives vary widely among government, energy companies, local communities, non-governmental organisations (NGOs), scientific bodies and the media.

The Energy Institute (EI) is the leading chartered professional body for the energy industry. It aims to develop knowledge about energy and promote wider understanding. This publication addresses the scientific and technological aspects of shale gas and its development. It provides a factual, balanced explanation of the major issues to be considered in the debate about the role of shale gas in meeting future UK energy needs.

The development of this guide has involved an extensive review and analysis of relevant literature. The document has been through a robust peer review process, with contributions from over 75 subject specialists, including professionally qualified Fellows and Members of the EI, with a broad range of backgrounds and extensive experience. The information, suitable for non specialists, is presented in a format intended to be accessible, neutral and based on sound science.

Finally, the document has been approved by the EI's Energy Advisory Panel (EAP). We intend the result to be a high quality document that allows the reader to understand the subject with scientific and technical accuracy, in order to use that knowledge as a basis for informed discussion.

Professor Jim Skea CBE FRSA FEI

Professor of Sustainable Energy in the Centre for Environmental Policy, Imperial College London, EI President-elect, and Chair, EI Energy Advisory Panel

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This edition was researched and developed by the EI Knowledge Service Team with substantial input from EI Fellows and Members with subject expertise, whose contribution is gratefully acknowledged.

This guide contains a number of technical terms. Where possible the EI has defined these. For all terms emboldened in the text, a more complete definition can be found in the Glossary.

Further information can be found on the Energy Matrix:
knowledge.energyinst.org

First edition 2015

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ISBN 978 0 85293 701 3

Published by the Energy Institute.

1. Shale gas.

What is it and where does it come from?

Shale gas is natural gas formed and held within shale formations. It is a fossil fuel originating from plant, algal or other remains, and composed primarily of **methane** (CH_4). Generally, shale formations are composed of fine-grained (less than 0.0039 mm in diameter) laminated sedimentary rocks made up of clay minerals (at least 30%), quartz, and small quantities of fossils, organic matter, carbonates, feldspars and other minerals. Gas shale formations are normally black due to the high organic matter content, although other colours can occur depending on their mineralogical composition.

Methane

The lightest and most abundant of the hydrocarbon gases and the principal component of natural gas.

Shales are formed by the weathering of rocks and the transport and eventual deposit of fine debris into lakes, lagoons, river deltas and the sea floor. Vast quantities of dead plankton or aquatic plant material are incorporated into the deposit, where **anaerobic** bacteria convert the remains into a waxy substance called **kerogen**.

Kerogen

A fossilised mixture of insoluble organic material that, when heated, breaks down into petroleum and natural gas.

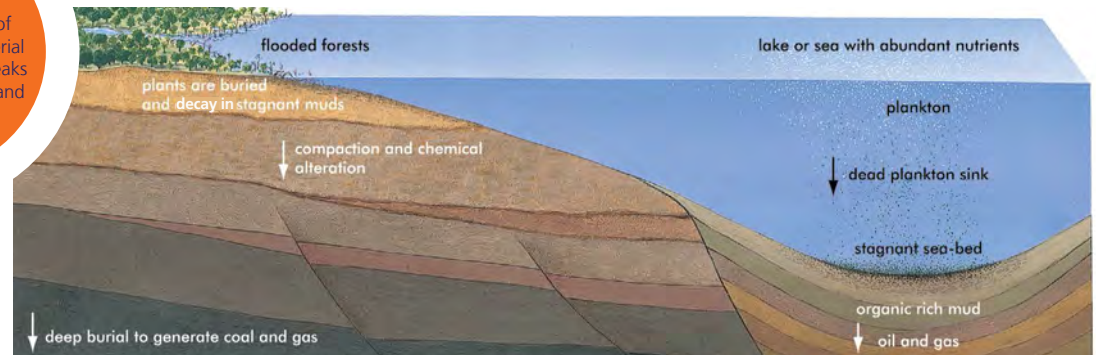
Adsorption

A process where molecules of gas or liquid are held on the internal and external surfaces of another material.

Depending on movement in the Earth's crust and changes in climate, there are variations in the rate and type of debris, and other sedimentary rocks such as sandstones or limestones can be deposited. As **sediments** are buried deeper underground, they are subjected to increased temperature due to the Earth's subsurface temperature gradient, and increased pressure due to the weight of accumulated sediments. This causes the sediments to compact and cement into rock. At temperatures above 50°C (122°F), kerogen begins converting into oil (catagenesis).

If the shale formation is buried deeper underground, and reaches a depth where the temperature is above 150°C (302°F), oil begins converting into **natural gas** (metagenesis). Ongoing burial, rock compaction and earth movement together with continued **hydrocarbon** generation causes the migration of oil and natural gas from shale.

However, some oil or natural gas will always be retained within the shale, **adsorbed** on to kerogen and clay particles, and filling pore spaces and natural fractures. It is this process that forms a potential shale oil or shale gas reservoir.



How is shale gas different from conventional gas?

The natural gas contained in shale reservoirs has the same primary chemical composition as the natural gas contained in conventional reservoirs – normally up to 95% methane. The main difference is in the geological and physical properties of the reservoirs in which the natural gas is stored rather than the composition of the gas itself. Shale reservoirs are often classified as ‘**unconventional**’ because they contain oil and natural gas that were generated in the shale itself, and because they do not naturally have sufficient **permeability** to allow the oil and gas to flow at commercial rates.

Unconventional gas generally occurs in very low permeability reservoirs (normally less than 0.1 millidarcy [mD]) with smaller, fewer or less interconnected pores, where fluids can barely flow. Shale gas reservoirs have especially low permeabilities, on the order of 0.001 mD.

In order to recover the natural gas contained in these reservoirs, the effective permeability is increased by creating high conductivity channels in the form of fractures. These new paths allow the natural gas held in the reservoir to be released and recovered through the well up to the surface.

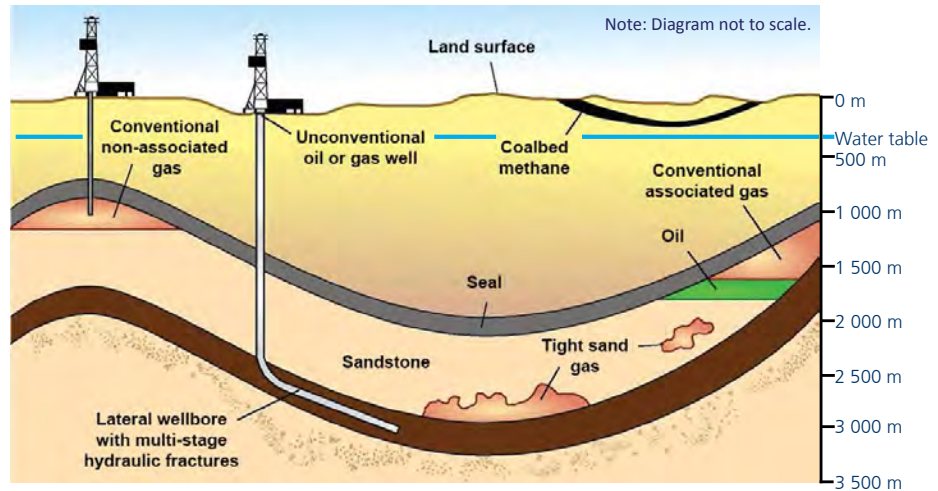
On the other hand, conventional gas is located in higher permeability reservoirs (normally more than 0.1 mD) in geologic structural traps. These traps can include **faults** and **anticlines**, and stratigraphic changes of rock types (e.g. sandstone **pinching out** to shale or clay). These reservoirs tend to have many large, well-connected pores and transmit fluids readily.

Permeability

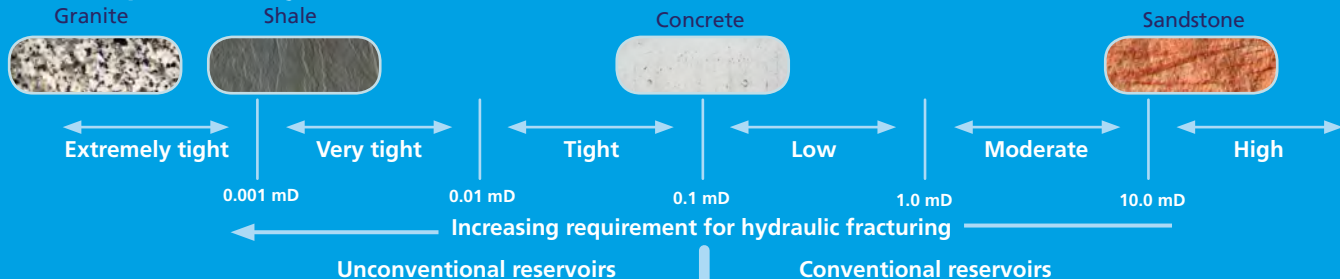
A measure of the ability of a porous material (such as rock) to transmit fluids.

Geology of conventional and unconventional oil and gas.

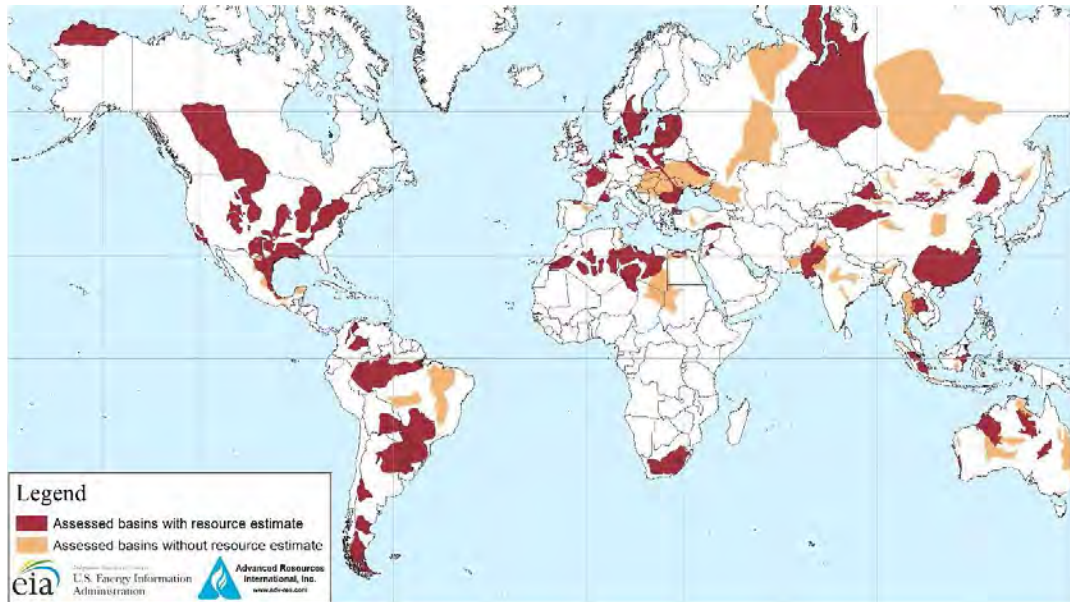
Note: Diagram not to scale.
Adapted from: US Energy & Information Administration (EIA)



Relative permeability scale



How abundant is shale gas?



Shale is the most common sedimentary rock, found in rock formations worldwide. Further exploration would likely lead to the discovery of prospective shale gas and other unconventional hydrocarbon reservoirs in most parts of the world.

Map of basins with assessed shale oil and shale gas formations, as of May 2013

Source: United States basins from EIA and US Geological Survey (USGS); other basins from Advanced Resources International (ARI) based on data from various published studies.

Top 10 countries (in terms of technically recoverable shale gas resources)

Source: EIA estimates, 2013

| Rank | Country | Shale gas tcf (tcm) |
|------|--------------------|----------------------|
| 1 | China | 1,115 (31.6) |
| 2 | Argentina | 802 (22.7) |
| 3 | Algeria | 707 (20) |
| 4 | US | 665 (18.8) |
| 5 | Canada | 573 (16.2) |
| 6 | Mexico | 545 (15.4) |
| 7 | Australia | 437 (12.4) |
| 8 | South Africa | 390 (11) |
| 9 | Russia | 285 (8.1) |
| 10 | Brazil | 245 (6.9) |
| | Others | 1,535 (43.5) |
| | World Total | 7,299 (206.7) |

Natural gas consumption by country

(excludes natural gas converted to liquid fuels)

Source: BP Statistical Review of World Energy, June 2014

| Country | Annual gas consumption, 2013 tcf (tcm) |
|--------------------|--|
| US | 26.02 (0.74) |
| Russia | 14.6 (0.41) |
| China | 5.69 (0.16) |
| Japan | 4.12 (0.12) |
| Canada | 3.65 (0.10) |
| Germany | 2.96 (0.08) |
| UK | 2.59 (0.07) |
| France | 1.5 (0.04) |
| Others | 57.07 (1.62) |
| World Total | 118.22 (3.35) |

tcm

Trillion cubic metres

tcf

Trillion cubic feet

Where might shale gas be found in Great Britain?

Great Britain has substantial volumes of shale gas and shale oil resources within **Carboniferous** and **Jurassic**-age formations, distributed broadly in its northern, central and southern regions.

The Department of Energy and Climate Change (DECC) recently commissioned the British Geological Survey (BGS) to perform three studies of shale gas resources in Great Britain: the Carboniferous Bowland-Hodder shales in central Britain (released in June 2013); the Jurassic shales in the Weald Basin of southeast England (released in May 2014); and the Carboniferous shales of the Midland Valley of Scotland (released in June 2014).



The first study encompassed the Bowland Shale Formation and its equivalents, together with older shales which are similar to those found in the Hodder Mudstone Formation. The study divided the shale **play** into the Upper Unit, which is typically up to 500 ft (150 m) thick, and the Lower Unit, which may reach a thickness in excess of 10,000 ft (3,000 m). The latter represents greater potential than the Upper Unit, but also a greater uncertainty of resource estimates because few wells have extended to its depths. The central estimate of the study indicated that there could be 1,300 tcf (37.6 tcm) of natural **gas in place** (GIP). The lower and upper estimates are 822 tcf (23.3 tcm) and 2,281 tcf (64.6 tcm) respectively.

The Jurassic shales in the Weald Basin (Southeast England) present shale oil potential. The lower and upper estimates of oil in place (OIP) are 2.20 billion barrels (bn bbl) (293 million tonnes [Mt]) and 8.57bn bbl (1,143 Mt), but the central estimate for the resource is 4.4bn bbl (591 Mt). No significant gas resource is recognised using the current geological model, primarily because the shale is not thought to have reached the geological maturity required to generate natural gas.

The third BGS study covers the Carboniferous shales of the Midland Valley of Scotland, and suggests a modest amount of shale gas and oil in place. The central estimate of GIP is 80.3 tcf (2.27 tcm), where the lower and upper estimates are 49.4 tcf (1.4 tcm) and 134.6 tcf (3.81 tcm) respectively. The central estimate of OIP is 6bn bbl (793 Mt), where the lower and upper estimates are 3.2bn bbl (421 Mt) and 11.2bn bbl (1,497 Mt) respectively. Due to limited good quality data and complex geology, there is a higher degree of uncertainty with this shale gas and shale oil resource estimation than the previous Bowland-Hodder and Weald Basin studies.

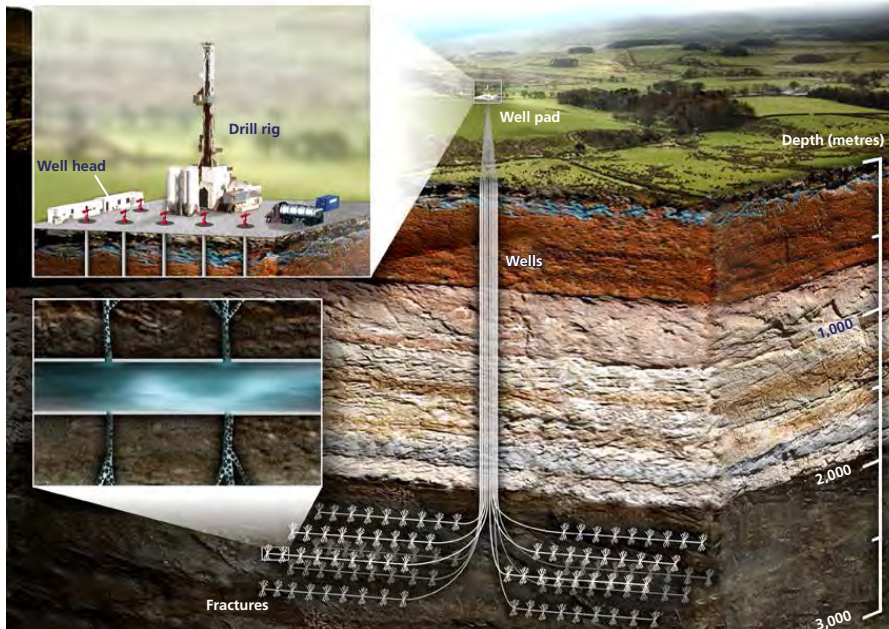
For each of the three BGS studies, figures for volumes of natural gas and oil in place represent the total amount of petroleum resources present in the rocks. It is not known what percentage of these resources are **technically** and **economically recoverable**. More data from drilling and production rates are needed in order to estimate a **recovery factor**, as well as more reliable figures for reserves, GIP, and OIP. By way of indication, the Marcellus shale in the US has a typical recovery factor in the range of 20 - 40%. Actual recoverable amounts are dependent on factors such as the specific reservoir geology, access to the reservoir, and gas market prices.

2. How is shale gas produced?

Shale gas, i.e. natural gas, can be produced from gas-containing shale formations by a combination of horizontal drilling followed by **hydraulic fracturing** (otherwise known as fracking, fracing or fracing). Using this combination of technologies, natural gas contained in the low-permeability shale reservoirs can be recovered and economically produced, but only if flow rates are sufficiently large and sustained, and gas prices are favourable.

The process for drilling, completing and testing a well is described as follows:

Example well diagram, illustrating horizontal drilling and hydraulic fracturing from a multi-well pad



1. Well construction

An exploration site requires an access road and an area of approximately two hectares (five acres) for the rig and associated equipment. A well is drilled in stages, each diameter smaller and deeper than the previous one. During drilling, mud is circulated through the **drill string** and back to the surface to remove **drill cuttings**, cool the **drill bit** and stabilise the **wellbore**.

Once each stage of the well is drilled, high strength steel pipe (casing) is run to the drilled depth and hung from the surface **wellhead**. Cement is pumped down the casing and up the outside **annulus**. Once the cement has hardened, the casing and cement are pressure tested to confirm there is a protective barrier. Thus, the casing and cement help maintain the control of the well, and provide a multilayer barrier to prevent fluids from escaping into freshwater aquifers. The next stage of drilling continues with a smaller sized bit from the bottom of the cemented steel casing.

2. Horizontal drilling

Shale gas reservoirs usually extend horizontally over many square kilometers, and are vertically very thin by comparison. Horizontal drilling is therefore used to place the **borehole** in contact with two or more kilometres of reservoir compared to a vertical well which could only contact a much smaller portion of the reservoir.

A vertical well is drilled to just a few meters above the shale gas reservoir, normally to a depth of greater than 5,000ft (1,500m). At this depth, and using special drilling equipment above and near the drilling bit (geo-steering, formation logging sensors, and other state-of-the-art technologies), the wellbore is deviated from its vertical plane at a prescribed rate until it is horizontal or nearly horizontal, depending on the planned well design. Drilling continues within the horizontal section (also known as the lateral section) until the planned length of this section is obtained.

Typically a single **well pad** contains 4-6 wells, which are horizontally drilled in different directions. These pad drilling techniques, widely used in the industry, minimise the operational footprint at the surface. If surface constraints exist, production can be concentrated in a smaller number of pads, which could potentially each contain up to 40 wells.

Timescale of operations

Pad preparation

3 weeks

Drilling per well

4-5 weeks

5 days
Hydraulic fracturing
per well

Flowback period

2-3 weeks

Source: Strategic Environmental Assessment for Further Onshore Oil and Gas Licensing, DECC

3. Well completion and stimulation

Once the drilling process is completed, the lateral section in contact with the shale reservoir is usually completed with cemented casing, an uncemented liner sleeve, or can be left un-cased (i.e. left as an open hole), depending on the rock properties and well design. The **drilling rig** normally moves off at this stage and hydraulic fracturing equipment is mobilised. The main components of this equipment include pump trucks, storage and mixing tanks, and a coiled tubing unit.

Most of the horizontal portion of the well is perforated in predetermined segments or intervals using a perforating tool or **abrasive perforating methods**. The perforations extend through the casing several inches into the targeted reservoir zones to provide entry points for the fracturing fluid and **proppant**. Perforation begins at the bottom of the well and gradually moves backward until the desired portions of the well are perforated. The perforating tool is then removed, and the hydraulic fracturing process starts.

A planned volume of fracturing fluid and proppant is pumped at high pressure into each perforated interval, opening up and then propping open induced and natural reservoir fractures. This staged process is repeated for each interval moving backwards through the horizontal portion of the well. Different technologies and techniques are used depending on the characteristics of each shale formation.

Cross-section of multiple steel casings with cement between them

Source: Virginia Department of Mines, Minerals and Energy (DMME)



4. Flow testing

Once the hydraulic fracturing operation is complete, the well is cleaned out, a production tubing assembly is lowered into the well, and a wellhead is installed. A temporary separator vessel is set up next to the well to separate and measure the volume of fracturing fluid that flows back up the well (**flowback fluid**), and gas and/or oil from the reservoir. Flowback of any residual proppant is separated in a sand trap upstream of the separator.

Flowback fluids are recycled or taken to a licensed treatment plant to yield water suitable for other uses. Depending on country-specific regulations, they could also be injected into deep, depleted hydrocarbon or saline reservoirs via dedicated disposal wells. However, this is prohibited in the EU by the Water Framework Directive (2000/60/EC) and subsequent 2012 Environmental and Human Health risk assessment.

Gas associated with **produced water** may be flared if no gas transportation pipelines are available. Any associated oil is taken to a licensed oil processing plant (refinery) via pipeline, truck, or rail depending on the available infrastructure in the area.

5. Long term production

The processes described so far are concerned with shale gas exploratory, appraisal and initial production development operations.

Industry expectation is that shale gas wells can produce for up to 20-25 years. Very little surface plant is needed during the production phase. Wells may be restimulated by additional fracturing 4-5 years after initial drilling.

In the US, experience has shown that once a well no longer produces at an economic rate, the wellhead is removed, the wellbore is filled with cement to prevent any leakage, and the surface is reclaimed to an agreed condition.

Additional details of long term production are outside the scope of this document. More information about long term production and field development in the UK is available from the Office of Unconventional Gas and Oil (OUGO).

Proppant

Specifically-sized particles, often sand grains, mixed with fracturing fluid that hold fractures open after a hydraulic fracturing treatment.

Chemical use in hydraulic fracturing

Certain chemicals are needed to ensure that the hydraulic fracturing process is efficient and effective. The primary chemicals used for hydraulic fracturing operations are gelling agents, friction reducers, biocides, **corrosion** inhibitors, oxygen scavengers, and acids – all commonly used in other sectors of the petroleum industry and elsewhere in everyday life.

In the UK, approximately 0.25% of the total volume of fracturing fluid consists of chemicals, the rest being water (~95%) and proppant (~5%). Regulators such as the Environmental Agency (EA) and Scottish Environment Protection Agency (SEPA) require operators to disclose the chemical constituents in fracturing fluids.

In the US, the concentration of chemicals can reach up to about 2% of the total volume of fracturing fluid. The exact constitution of fracturing fluid depends on the characteristics of the formation. A growing number of states currently require operators to divulge the chemicals used; to increase transparency, most operators disclose the chemicals used through the publically available FracFocus Chemical Disclosure Registry.

Gelling agent

Reasons for use

Improves proppant placement

Consequences of not using chemical

Increased water use, natural gas recovery may decrease in some cases by 30 to 50% when fracturing fluids are not gelled

Other uses

Used as a thickener in cosmetics, ice cream, toothpaste, sauces

Acid

Reasons for use

Cleans mineral deposits from rock formations enabling more efficient production

Consequences of not using chemical

Higher treatment pressures required, reduced production efficiency

Other uses

Used as swimming pool cleaner, household cleaner, and in cosmetics

Oxygen scavenger

Reasons for use

Prevents corrosion of well tubing and casing by oxygen

Consequences of not using chemical

Corrosion sharply increased, well integrity (containment) potentially compromised

Other uses

Used in food packaging to aid preservation; aids in the protection of boilers from corrosion

Biocide

Reasons for use

Controls bacterial growth which causes blockages

Consequences of not using chemical

Higher treating pressure, possible growth of bacterial sludge within the well causing plugging of perforations

Other uses

Used in drinking water, cosmetics and wipes, cleaning products, toothpaste, laundry detergents and general disinfectants

Friction reducer

Reasons for use

Decreases pumping friction

Consequences of not using chemical

Significantly increased surface pressure and hydraulic fracture pump engine emissions

Other uses

Used in cosmetics, including hair, make-up, nail and skin products

Corrosion inhibitor

Reasons for use

Used in conjunction with acid to prevent corrosion of pipes

Consequences of not using chemical

Sharply increased risk of pipe corrosion from acid, well integrity potentially compromised

Other uses

Used in pharmaceuticals, acrylic fibres and plastics

Sources:
DECC, Canadian Society for Unconventional Gas (CSUG), Canada
Frac Focus Chemical Disclosure Register, www.fracfocus.org

3. What are the potential impacts of shale gas?

Tension exists between improved energy security and other potential benefits of UK shale gas development, and the environmental risks and possible adverse impacts of shale gas on achievement of a low carbon economy. At this early stage of development, it is difficult to predict the extent to which these impacts will affect the UK.

Greenhouse gas emissions

When natural gas is burned, the amount of carbon dioxide (CO₂) emitted per unit of energy released is lower than any other fossil fuel (see table). Therefore, when used as a substitute for coal or oil for heat and power generation, it contributes to a reduction in CO₂ emissions, assuming the life cycle emissions are lower for natural gas than for oil or coal.

Source: *Potential Greenhouse Gas Emissions Associated with Shale Gas Extraction and Use*, MacKay and Stone, September 2013

Between 2008 and 2013, the CO₂ emissions from electricity generation in the US fell by 321 MtCO₂ (a 13.5% reduction), partly due to this change in fuels. The so-called 'shale gas boom' took off in 2008 and drove down US natural gas prices. Subsequently, the share of electricity generation from gas-fired power plants increased at the expense of coal-fired power plants. Source: *Monthly Energy Review*, US EIA, July 2014

This price-driven fuel switching is unlikely to occur in the UK (see page 10). However, the UK's 2008 Climate Change Act includes a commitment to reduce UK greenhouse gas emissions to at least 80% lower than 1990 levels by 2050. To meet these climate targets, policy-driven fuel switching is likely to occur in the UK, followed by a reduction in the use of fossil fuels or by widespread use of carbon capture and storage by the 2030s. Natural gas may thus be used in the transition to lower-carbon electricity generation or for heating; however, the extent to which shale gas will impact on the UK's climate targets is yet to be determined.

Sources: *The UK's Global Gas Challenge*, UKERC, November 2014; *Meeting Carbon Budgets - 2014 Progress Report to Parliament*, CCC, July 2014

| Fuel type | Grams of CO ₂ emitted per kilowatt-hour (kWh - thermal) | CO ₂ emitted relative to natural gas |
|-------------------------------|--|---|
| Natural gas | 184 | 1 |
| Liquefied Petroleum Gas (LPG) | 214 | 1.16 |
| Motor gasoline | 240 | 1.3 |
| Heavy fuel oil | 268 | 1.46 |
| Bituminous coal | 307 | 1.67 |

Note: All emission factors are based on gross calorific value
Source: Digest of UK energy statistics (DUKES) 2013

Security of supply

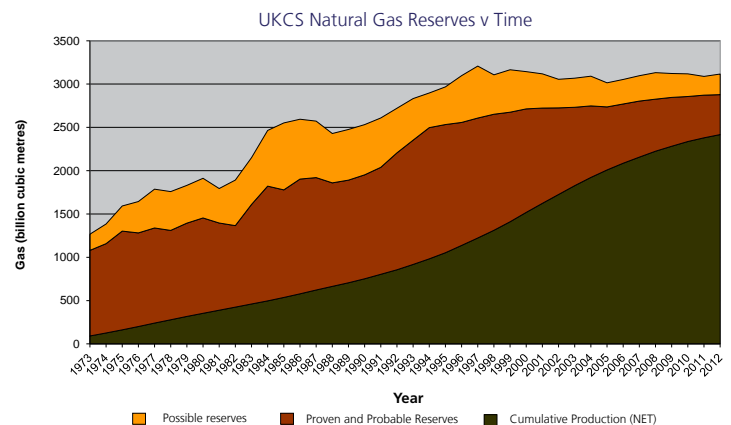
Security of energy supply is an issue facing many countries. The UK situation is one example of how shale gas could help address security of supply challenges.

The UK is now facing a decline of domestic conventional gas reserves and a corresponding fall in production. Production of natural gas from the UK Continental Shelf (UKCS) has been decreasing by 9.2% on average per annum since 2000 (see chart below).

Since then, Liquefied Natural Gas (LNG) and pipeline gas imports have been increasing and, by 2019, it is expected that they will account for 69% of UK gas supply. In 2012, about 65% of total gas consumed was imported.

Any indigenous energy source has the potential to enhance the UK's self-sufficiency in energy, whilst also increasing the diversity of supply. Domestic UK shale gas production could potentially contribute to both of these aims.

This could also have implications for the economic aspects of supply security, such as minimising the import payments for fuel.



Source: DECC

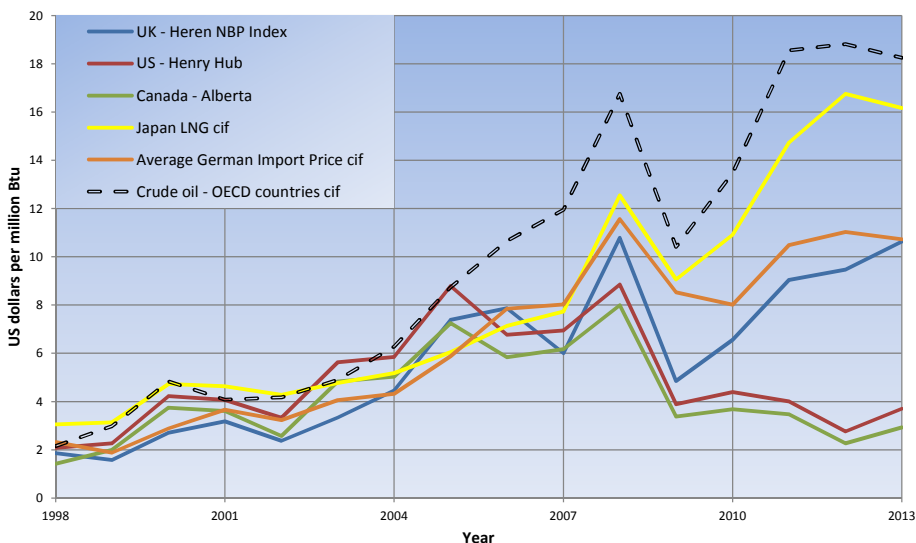
Gas prices and potential effects on manufacturing

The graph below shows the evolution of natural gas and oil prices since 1998. Global prices have diverged since the late 1990s. This is due to a number of different factors. For example, the high Japanese LNG price is due to its reliance on imported gas. The low North American gas prices are closely related to low export capacity and high indigenous supply.

The UK and Europe have a high import/export capacity, making prices similar across Europe. This trading capacity limits the UK's ability to price differently from the rest of Europe. For this reason, additional UK gas production is likely to only have a modest effect on these internationally-set gas prices. In addition, global demand for gas is expected to increase, which could further limit any reduction of the price of gas in the UK.

At this stage, not enough is known about UK shale gas resources to clearly define the impacts they would have across the economy. For example, the chemical composition of the natural gas can be important for petrochemical feedstocks and the industries that use them.

One example of a petrochemical with potential to be impacted by shale gas production is **ethylene**, a basic chemical used in thousands of everyday products such as plastic bags, milk cartons, insulating material, antifreeze, toys and car components. Ethylene can be derived from crude oil or natural gas through different chemical processes. Natural gas of the correct composition is a more efficient feedstock for ethylene production than other hydrocarbon feedstocks; therefore, increased supply could lower the cost of ethylene production. As yet, the composition of the UK's shale gas is unknown, and therefore the potential impact on ethylene production and other areas of the manufacturing sector is uncertain.



Source: BP Statistical Review of World Energy, June 2014
Note: cif = cost + insurance + freight (average prices)

Economic factors

The shale gas industry has the potential to generate substantial tax revenue for the UK. According to an independent study, shale gas development in the Bowland Basin could generate as much as £580 million in tax revenues per annum by 2020.

Source: *Potential Bowland shale gas development – economic and fiscal impacts*, Deloitte, 2013

In the US, the shale gas contribution to the national Gross Domestic Product (GDP) was around \$76 billion in 2010, and is projected to rise to \$231 billion in 2035. The industry is expected to generate more than \$930 billion in federal, state, and local tax and royalty revenues over the next 25 years. These revenues will be generated by natural gas producers, their employees, the supply chain, and other ancillary companies.

Source: *The Economic and Employment Contributions of Shale Gas in the United States*, IHS, 2011

The UK government has proposed that local authorities should receive a large portion of business tax raised from shale gas projects. It is the government's intention that operators will provide at least £100,000 of benefits per fractured well site during the **exploration phase**, and no less than 1% of overall revenues, to local authorities.

Job creation

Job creation is likely to result from shale gas exploration and production stages in the UK. The number of potential jobs will vary depending on several factors, therefore figures are uncertain at this stage.

According to one DECC report, the number of full time equivalent positions created (including direct and indirect staff) would range from 1,100 to 4,200 during the first year, reaching a peak of between 2,600 and 32,000 after six or seven years. Other estimates put the peak figure above 64,000. This is projected to gradually decline over the following few years.

It is difficult to predict how many of these jobs would be sourced from local communities. The first hydraulically fractured shale gas well drilled in the UK, at Preese Hall in Lancashire, sourced approximately 15% of its workforce from its local community. However, this cannot be assumed to be consistent for all communities.

Sources: *Strategic Environmental Assessment for Further Onshore Oil and Gas Licensing*, DECC; *Getting ready for UK shale gas*, EY for UKOOG, 2014

In the US, about 600,000 people were employed in the shale gas industry in 2010. This is expected to rise to 1.8 million by 2020.

Source: *The US Natural Gas Revolution: What it means for jobs and economic growth*, IHS, 2014

Induced seismicity

Small magnitude seismic events normally occur during hydraulic fracturing operations. With a few exceptions, they are too small to be felt, and none of them have been large enough to cause structural damage at the surface.

Source: USGS

The first UK hydraulic fracturing operation in Lancashire induced a number of small tremors (top local magnitude values of 1.5 and 2.3 - Source: BGS), but no surface damage was reported. Similar magnitude tremors occur during coal mining, oil and gas field depletion, filling of large water reservoirs, and deep geothermal energy projects.

Further minor seismic events are expected in the UK during hydraulic fracturing operations. In order to accurately control this induced seismicity, the DECC plans to require operators to:

- conduct a prior review on seismic risk and submit a plan showing how this is to be addressed.
- monitor seismic activity before, during and after hydraulic fracturing.
- implement a 'traffic light' system to identify unusual seismic activity requiring the reassessment or halting of operations.

Local magnitude (M_L) scale

2.5 or less
Usually not felt, but can be recorded

2.5 - 5.4
Often felt, but only causes minor damage

5.5
Slight damage to buildings

8 or greater
Can destroy communities

Logistics

Site traffic

During the exploration and production stages the number of vehicle movements can be significant. This in part depends on the number of wells per well pad. Estimates are shown in the table to the right.

By way of comparison, a small UK supermarket receives approximately 3-6 deliveries per day, while a large supermarket may receive between 4-20 deliveries daily, depending on a range of factors.

Pipeline network

The natural gas produced from shale needs to be transported from the well pad to a pipeline network. In the UK, existing network arrangements for gas entry to the National Transmission System and Distribution Network will apply.

If shale gas becomes a significant contributor to UK gas supplies, National Grid considers that this would need to be taken into account for future network investment.

Source: *The Economic Impact on UK Energy Policy of Shale Gas and Oil*, House of Lords, October 2013

The vehicle movement numbers in the table include the number of water trucks needed to deliver water to the site. Instead of trucks, pipelines can also be used to transfer water to drill sites. This reduces the truck trips required, but could impact the cost.

Health and safety

The main hazard at every well site is the potential for uncontrolled release of hydrocarbon gas due to a failure of the well structure, which may then reach a source of ignition leading to a fire or explosion.

The level of risk varies, depending on how quickly and easily any release can be controlled, and on geological conditions. Where there is a loss of well integrity, there is also the possibility of fracturing fluids or produced water being released to the surrounding rock strata or to the surface, which may have health or environmental consequences depending on the location of water aquifers. A well-designed and constructed well will help to reduce the risks of a release of fluids or gas to as low as is reasonably practicable.

For shale gas operations, the UK Health and Safety Executive (HSE) regulates to ensure that wells are properly designed, constructed, operated, maintained, and ultimately abandoned to ensure that the flow of fluids in the well, including fracturing fluids and produced gas or water, are controlled and stay within the well.

Companies are also required by the HSE to employ an independent examiner (separate from the immediate line management of the well operator), to assess well design, construction, operation and maintenance. The well examination scheme and involvement of the well examiner continues for the complete lifecycle of the well, from design to final plugging and decommissioning.

| Statistic | Exploration | Production development | |
|---|-------------|------------------------|-----------------|
| | | Low activity | High activity |
| Total number of wells per pad | 1 | 5 – 11 | 23 |
| Frequency of vehicle movements per well pad (per day) | 14 – 36 | 16 – 48 | 17 – 51 |
| Total duration of activities at well pad (weeks) | 12 – 13 | 37 – 73 | 122 – 145 |
| Total vehicle movements per well pad | 840 – 2,340 | 2,960 – 17,520 | 10,370 – 36,975 |

Adapted from: *Strategic Environmental Assessment for Further Onshore Oil and Gas Licensing*, DECC



Methane emissions

Methane is a much more potent greenhouse gas than CO₂, but has a shorter lifetime in the atmosphere (a half-life of about seven years vs. more than 100 for CO₂). International bodies calculate global warming potential (GWP) differently, but it is estimated that methane presents between 21 and 34 times more GWP than carbon dioxide.

Source: IPCC

Potential methane emissions from exploration, production, transport and end use, have four main sources:

Intentional venting of gas for safety or economic reasons

Venting can occur during well completions, including post-hydraulic fracturing, **flowback** of fracturing fluids, and as part of equipment maintenance operations. However, this will not be permitted in the UK where all operators will be required to flare or capture any vented gas.

Fugitive emissions

This type of emission may occur as leaks in pipelines, valves, or seals, either accidentally (e.g. from corrosion or physical damage), or from equipment design (e.g. rotating seals).

Clear guidelines exist in the UK to control and minimise these emissions.

Incidents involving rupture of confining equipment

This equipment might include pipelines, gas processing plants, compressors, pressurised tanks, or well isolation equipment.

Incomplete burning

The effectiveness of burning gas in flares varies according to wind and other conditions, and is typically no better than 98% (a similar effect can be seen when starting a gas stove: it can take a few seconds before a steady flame is established).

In the UK, **flaring** and combustion systems must be approved by the appropriate regulatory body.

The majority of potential methane emissions could theoretically be controlled by implementing improved industry-wide methane-capture technology. This includes safety procedures, applications and equipment (e.g. reduced emissions completions or 'green completions'). These technologies are currently being installed by operators in the US.

Conventional production methods also have to manage these potential emission risks. Processing, compression and transportation challenges are common to conventional and unconventional gas.

Good practices for environmental management backed up by strong regulation and high quality data are necessary to understand background levels, set baselines for, and minimise potential methane emissions.



Water management

When evaluating the potential impacts of shale gas development on water resources, the main aspects to consider are water resource requirements, water quality, and wastewater management.

In the UK, the estimate of water needed over the lifetime of each well will vary depending on shale formation depth, geology and other parameters. This will range from 1.6 to 6 million gallons (7,250m³ to 27,000m³) (BGS estimates). As a reference, an Olympic swimming pool has a capacity of around 0.55 million gallons (2,500m³) of water.

To put this into perspective, for shale gas to meet 10% of the UK gas demand for the next 20 years (assuming a total gas demand of 3.20 tcf or 90 billion m³ per year), then 264 to 352 million gallons (1.2 to 1.6 million m³) of water would be required every year. Although this may sound like a large amount, it equates to less than 1/10th of 1% of total licensed water **abstraction** per year in England and Wales, which is about 2,770,000 million gallons (12,600 million m³). Potential water use is therefore low in national terms, but there could be local or regional consequences should a large industry develop which will have to compete against different users.

Source: *Shale Gas and Water*, CIWEM

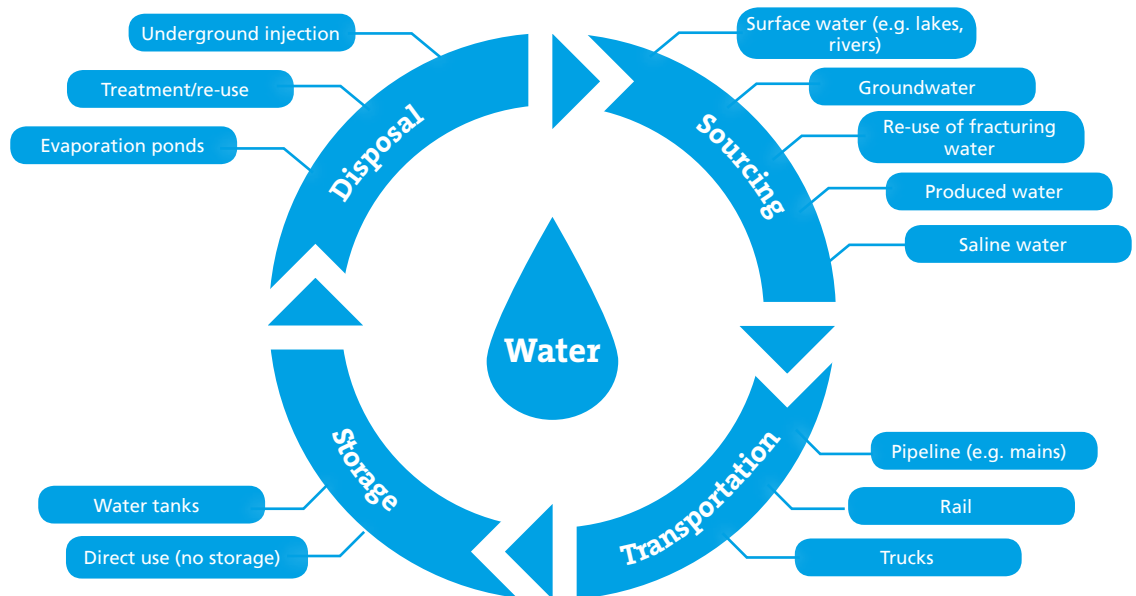
The risks related to water quality, particularly groundwater, arise from three main sources:

- surface spillages of chemicals, diesel, flowback fluids, and other materials at a drilling site.
- poor well design and construction with subsequent failure and subsurface release of contaminants.
- propagation of fractures during hydraulic fracturing. Note that the risk of fractures reaching overlying fresh water aquifers is extremely unlikely (Source: *DEI Briefing Note No. 902*, Durham Energy Institute). Maps showing the relative proximity of shale layers and aquifers are available from the BGS.

Flowback fluids may contain substances which are harmful to the environment if not properly managed. These substances may include natural gas and other hydrocarbons, minerals, salts, small traces of naturally occurring radioactive material (NORM) or heavy metals (if present in the shale formation).

These fluids must be managed, handled, and treated properly to avoid surface pollution and to reduce methane emissions. In the UK, operators are required to store these fluids in surface tanks before re-using or transferring them to a treatment plant. Treated water can subsequently be used elsewhere.

The water cycle during the whole process is described as follows:



Adapted from: Unconventional gas and hydraulic fracturing: Issue briefing, BP

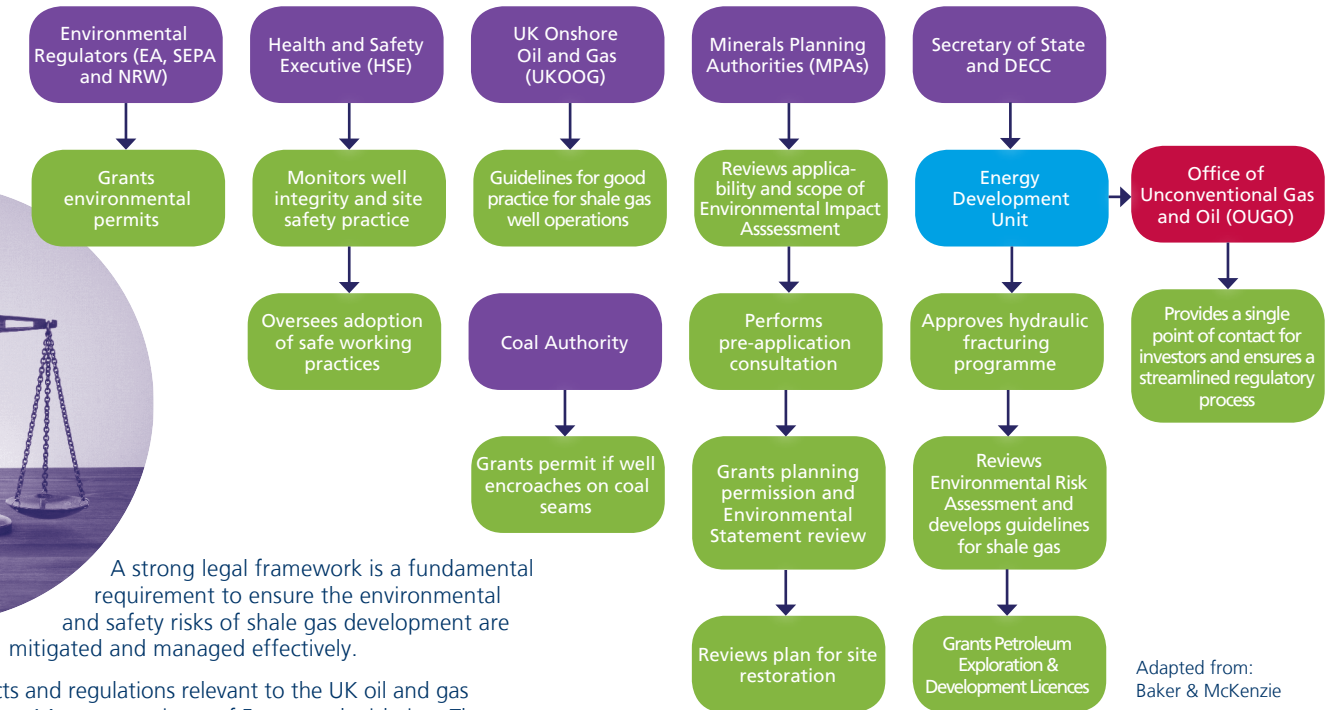
Flowback fluids

The mixture of fracturing fluid and produced water.

Produced water

The water that returns from the well along with the natural gas after hydraulic fracturing has taken place.

4. Legal framework, control and administration



There are 16 Acts and regulations relevant to the UK oil and gas industry as well as 14 separate pieces of European legislation. These are not specific to shale gas, but are applicable to any oil and gas activity during exploration and production. This legal framework includes the Petroleum Act 1998, the Environmental Planning Regulations 2010, and the Town and Country Planning Act 1990. These are governed, overseen and supported by several regulatory and administrative bodies.

The chart above shows the roles and responsibilities of regulatory and administrative bodies for oil and gas onshore exploration and **appraisal phases** in the UK.

Once commercial viability of the development has been determined, planning consent will be sought for a full production site. A new Environmental Impact Assessment (EIA) and a Field Development Plan (FDP) will be submitted to the relevant authorities. The submission of the FDP by the operator marks the start of the **production phase**. At this stage, associated equipment, such as pipelines and gas processing facilities, will be constructed, subject to the successful completion of additional planning applications.

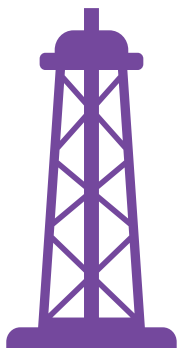
Ownership of resources and fiscal support

In the UK, as outlined in the Petroleum Act, all mineral rights, including shale gas, are entrusted to the Crown, and licences for oil and gas exploration and production are granted by DECC and the Secretary of State for Energy and Climate Change. Permission to commercially operate must still be obtained from the respective local authority. Consent from landowners is currently required for vertical drilling and, importantly, from any landowner under whose land there will be horizontal drilling. However, in a proposed change to existing trespass laws, companies are likely to be allowed to drill horizontally at depths greater than 300 metres under privately owned land.

In order to incentivise early investment in exploration for and development of shale gas in the UK, the government has put in place new fiscal incentives. This reduces the tax burden from the current level of 62% to as low as 30% on onshore oil and gas profits.

5. Further opportunities, challenges and considerations

Scarcity of drilling and fracturing equipment in Europe



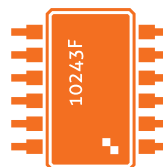
In 2012, the number of land rigs available in Europe was 72 compared to around 2,000 rigs in the US. The majority of the US rig fleet is being used locally, so European drillers would have to commission new equipment. Each rig takes an average of nine to 12 months to assemble, and this is a capital-intensive process. Unconventional gas production requires the drilling of many wells in a short time period to make it economically viable.



Discussing and understanding legislation

Some experts believe that the UK has strong existing oil and gas legislation that could be applied to new unconventional oil and gas exploration and production fields. On the other hand, some organisations, including several NGOs, are unsure if the current legislation is sufficiently strong to avoid further environmental or public health issues.

Further work is required in this area because a strong regulatory framework is necessary for ensuring responsible shale gas development.



Production technology development

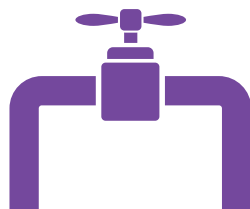
Currently, the maximum gas recovery factor from shale gas reservoirs is very low compared with conventional reservoirs. Continued innovation and development of production technologies could increase this recovery factor. Having more efficient production technologies could reduce the number of wells needed to produce the gas, reduce the amount of water needed per well, and reduce the number of truck movements. Such efficiency improvements are currently under development.

Monitoring the construction of wells



Well construction is one of the key aspects in avoiding environmental issues, such as groundwater contamination by hydrocarbons or other substances. Standards exist for casing design and performance, as well as cementing quality control. Transparent monitoring of well construction can help provide assurance and manage environmental risk.

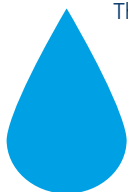
Improving methane emissions management



Methane emissions could counteract the potential reduction in national emissions from using shale gas instead of coal or oil (see section 3). Estimates of the volume of methane leaked or vented during the production and transportation of natural gas vary widely, particularly for shale gas wells. This is due to a longer well completion and **stimulation** stage than for conventional wells.

This is predominantly a data acquisition and management problem. It could be solved by regulators requiring operators to identify leaks, leading to the capture of emissions (e.g. through reduced emissions completions).

Monitoring water quality around producing wells



The monitoring of water quality will be an ongoing activity for UK regulators and shale gas operators, and a key concern for local communities. Some regulators in the US require monitoring of water quality pre- and post-fracturing in gas-producing areas. In the UK, the BGS has carried out work to establish a baseline for groundwater monitoring and protection. The latest data is available on the BGS website.



Enhancing water management

Fresh water is a limited resource. Several aspects of water management are being improved to minimise the impact of hydraulic fracturing on fresh water resources.

These include sea water sourcing and the re-use of flowback fluid, and the use of non-water based fracturing fluids, such as gels or gases. Other water management issues under consideration include transport and fluid composition disclosure, storage, treatment, and disposal.

Enhancing information exchange



The production of unconventional hydrocarbons can be divisive. During the last few years, various parties and interested groups have raised serious concerns about hydraulic fracturing and shale gas operations.

Dialogue between all parties is needed to ensure that local communities are well informed, understand the issues and opportunities from hydraulic fracturing operations, and are able to voice their concerns to regulators and operators.

6. Additional information

Additional sources

Advanced International Resources (ARI), US
Alberta Geological Survey (AGS), Canada
British Geological Survey (BGS), UK
Canadian Society for Unconventional Gas (CSUG), Canada
Centre for Climate Change Economics and Policy, UK
Department of Energy & Climate Change (DECC), UK
Department for Environment, Food and Rural Affairs (Defra), UK
Durham University, UK
Energy Information Administration (EIA), US
Energy Resources Conservation Board (ERCB), Canada
Energy-Future
Environment Agency (EA), UK
Environmental Protection Agency (EPA), US
ESCP Europe Business School, EU
European Resource Centre for Shale Gas, Tight Gas & Coalbed Methane, EU
Grantham Research Institute on Climate Change and the Environment, UK
Health and Safety Executive (HSE), UK
House of Commons, UK
IHS Global Insight
Institute of Directors (IoD), UK
International Gas Union (IGU), EU
National Atmospheric Emissions Inventory, UK
National Institute for Occupational Safety and Health (NIOSH), US
Northern Ireland Environment Agency (NIEA), UK
Occupational Safety and Health Administration (OSHA), US
Office of Unconventional Gas and Oil (OUGO), UK
Research Centre for Energy Management (RCEM), EU
Scottish Environment Protection Agency (SEPA), UK
The Chartered Institution of Water and Environmental Management (CIWEM)
The Royal Academy of Engineering, UK
The Royal Society, UK
TNO, Netherlands
US Geological Survey (USGS), US
UK National Statistics, UK
United Kingdom Onshore Oil and Gas (UKOOG), UK
World Petroleum Council (WPC)

Further reading (All of these documents can be accessed via the EI's **Energy Matrix***)

Shale gas extraction in the UK: a review of hydraulic fracturing; The Royal Society and The Royal Academy of Engineering, 2012
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Energy-future.com, 2013, *How the Energy Industry Works: The ultimate guide to energy*
Golden rules for a golden age of gas, world energy outlook, special report on unconventional gas; International Energy Agency, 2012
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About shale gas and hydraulic fracturing (fracking); Department of Energy & Climate Change, 2013
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Shale gas: an updated assessment of environmental and climate change impacts, Broderick, J et al, Tyndall Centre, University of Manchester, 2011
Understanding hydraulic fracturing; Canadian Society for Unconventional Gas, 2012
Journal of Petroleum Technology, Society of Petroleum Engineers
Measurements of hydraulic-fracture-induced seismicity in gas shales; Mar 2013, pg 149
Seeking lower-cost ways to deal with fracturing water; Nov 2013, pg 48
George P. Mitchell and the Barnett Shale; Nov 2013, pg 58
Cracking the Cline: A new shale play develops in the Permian Basin; Nov 2013, pg 70
Fracturing-treatment design and reservoir properties impact shale-gas production; Oct 2013, pg 134
Shale Technology Review; World Oil, Jul 2013,
Eagle Ford: Bakken in sight as play extends beyond core; World Oil, Aug 2013, pg 74
Niobrara: Independents unravel play, hike liquids production; World Oil, Sep 2013, pg 106
Regulation, profitability and risk - the shale gas conundrum, Petroleum Review, Oct 2013, pg 30
Regulation is the key to safe fracking; Geoscientist, Aug 2012, pg 8
Frac Focus Chemical Disclosure Register; fracfocus.org
Special Issue: Understanding the Risks of Unconventional Shale Gas Development; Stern, P C et al, Environmental Science & Technology 2014, 48, pgs 8287-8288.

* knowledge.energyinst.org

Glossary

Abstraction

The removal of water, permanently or temporarily, from rivers, lakes, canals, reservoirs or from underground strata.

Abrasive perforating method

A method that uses a special jetting tool at the end of jointed or coiled tubing. Abrasive slurry is pumped through the jetting tool and back up the wellbore. This cuts holes through the steel casing to allow fracturing fluid to flow into the shale formation.

Adsorption

The adhesion of an extremely thin layer of molecules of gas or liquid to the surface of another material.

Annulus

The space between two concentric objects, e.g. between the wellbore and casing or between casing and tubing, where fluid can flow.

Anoxic/anaerobic

Occurring in the absence of oxygen.

Anticline

An arch-shaped fold in rock in which rock layers bend downwards in opposite directions from the crest, with progressively younger rocks extending outward from the core.

Appraisal phase

In the oil and gas industry, the stage immediately following successful exploratory drilling. During this phase, delineation wells might be drilled to determine the size of the oil or gas field and how to develop it most efficiently.

Borehole

An uncased drill hole from the surface to the bottom of the well.

Carboniferous

The geologic period and system that extends from about 359 to 299 million years ago.

Corrosion

The gradual destruction of materials, including metal, due to chemical or electrochemical reactions.

Development operations (phase)

In the oil and gas industry, the stage that occurs after appraisal has proven successful, and before full-scale production.

Drill bit

The tool used to crush or cut rock on the bottom of the drillstring.

Drill cuttings

Small pieces of rock that break away due to the action of the drill bit.

Drill string

The combination of the drillpipe, the bottomhole assembly and any other tools used to make the drill bit turn at the bottom of the wellbore.

Drilling rig

The machine used to drill a wellbore.

Economically recoverable resources

Those which can be profitably produced under current market conditions. The economic recoverability of oil and gas resources depends on three factors: the costs of drilling and completing wells, the amount of oil or natural gas produced from an average well over its lifetime, and the prices received for oil and gas production.

Ethylene

A flammable hydrocarbon, occurring in natural gas, coal gas, and crude oil. It is used in chemical synthesis. Chemical formula: C_2H_4

Exploration phase

In the oil and gas industry, the stage where all efforts are made in the search for new deposits of oil and gas. This phase includes geological, geochemical, and geophysical exploration and drilling of exploration wells.

Fault

A fracture in the earth's crust accompanied by displacement, e.g. of the rock strata, along the fracture line.

Field Development Plan

All activities and processes required to develop an oil and gas field: economic, risk and environmental impact assessments, geological surveys, infrastructure design and construction, and logistics. FDPs must be approved by the relevant authorities before long term production can commence.

Flaring

The burning of unwanted gas through a pipe (also called a flare) in oil and gas operations. Flaring is a means of disposal used when there is no way to transport the gas to the market, and the operator cannot use the gas for another purpose.

Flowback

The process of allowing fluids to flow from the well following a stimulation treatment, either in preparation for a subsequent phase of treatment or in preparation for clean-up and returning the well to production.

Flowback fluids

The mixture of fracturing fluid and produced water.

Gas in Place (GIP)

Estimate of the total amount of gas that is held within a geological formation.

Hydraulic fracturing

A stimulation treatment routinely performed in oil and gas wells to facilitate higher production rates of reservoir hydrocarbons contained within a low-permeability reservoir. Specially formulated fluids are pumped at high pressure and rate into a reservoir interval causing vertical fractures to open radiating away from the wellbore. These are then filled with proppant to keep the fractures open after completion of the fracturing operation and during the production stage.

Hydrocarbon

Organic chemical compound containing only hydrogen and carbon atoms. There are a vast number of these compounds, and they form the basis of all petroleum products. They may exist as gases, liquids, or solids, e.g. methane, hexane, and asphalt respectively.

Jurassic

The geologic period and system that extends from about 202 to 147 million years ago.

Kerogen

A fossilised mixture of insoluble organic material that, when heated, breaks down into petroleum and natural gas. Kerogen consists of carbon, hydrogen, oxygen, nitrogen, and sulphur and is formed of compacted organic material, including algae, pollen, spores and spore coats, and insects. It is usually found in sedimentary rocks, such as shale.

Methane

The lightest and most abundant of the hydrocarbon gases and the principal component of natural gas. It is colourless, odourless and flammable. Chemical formula: CH_4

Natural gas

A naturally occurring mixture of hydrocarbon gases that is highly compressible and expandable. Methane is the chief constituent of most natural gas, with lesser amounts of ethane (C_2H_6), propane (C_3H_8), butane (C_4H_{10}), and pentane (C_5H_{12}). Impurities can also be present in large proportions, including carbon dioxide, helium, nitrogen and hydrogen sulphide.

Perforating gun

A special tool used for creating holes in the well's casing inside the producing formation. The gun, a steel tube of variable length, has steel projectiles placed at intervals over its outer circumference, perpendicular to the cylinder. The gun is fired electrically, shooting numerous holes in the casing that permit oil and gas to flow.

Permeability

A measure of the ability of a porous material (such as rock) to transmit fluids. It is primarily determined by the size of the pore spaces and their degree of interconnection. The most common units used to measure permeability are Darcys or milliDarcys (mD). It can also be measured in centimetres per second.

Pinch out

The disappearance or 'wedging out' of a porous, permeable formation between two layers of impervious rock. The gradual, vertical thinning of a formation over a horizontal or near-horizontal distance, until it disappears.

Play

Used in the oil and gas industry to refer to a geographic area which has been targeted for exploration due to favourable geo-seismic survey results, well logs or production results from a new well in the area, e.g. shale play.

Produced water

The water that returns from the well along with the natural gas after hydraulic fracturing has taken place. The water may be naturally occurring and may contain residual fracturing fluid.

Production phase

In the oil and gas industry, the stage that occurs after successful exploration and development, during which hydrocarbons are drained from an oil or gas field.

Proppant

Specifically-sized particles mixed with fracturing fluid that hold fractures open after a hydraulic fracturing treatment, e.g. sand.

Recovery factor

The proportion of total resource in place which is recoverable, normally expressed as a percentage.

Sediment

Unconsolidated grains of minerals, organic matter or rock, which can be deposited by water, ice or wind.

Stimulation

A treatment performed to restore or enhance the productivity of a well.

Technically recoverable resources

The volume of oil or natural gas that could be produced with current technology, regardless of oil and natural gas prices and production costs.

Unconventional

An umbrella term which refers to oil or gas occurring in reservoirs which, due to geological and physical properties, require non-traditional extraction or stimulation techniques in order to produce the oil and natural gas at economical rates. The definition of these types of reservoirs may evolve over time with technological and economic developments.

Wellbore

The drilled hole, including the uncased portion of the well.

Wellhead

The system of spools, valves and assorted adapters that provide pressure control of a production well.

Well pad

A temporary drilling site, usually constructed of local materials. After the drilling operation is over, most of the pad is usually removed or plowed back into the ground, in line with the Environmental Liabilities Directive.

Regulatory bodies

Department of Energy and Climate Change (DECC)

A department of the UK Government, DECC, through its Energy Development Unit, is responsible for licensing exploration and regulating development of the UK's oil and gas resources. DECC's Office of Unconventional Gas and Oil (OUGO), was established to act as a single point of contact for investors in unconventional hydrocarbons, reviews the regulations currently applying to unconventional hydrocarbons and ensures that any overlaps are rationalised. It also promotes the safe, responsible and environmentally sound recovery of the UK's unconventional hydrocarbons.

Environment Agency (EA), Scottish Environment Protection Agency (SEPA), and Natural Resources Wales (NRW)

Environmental regulators in England, Scotland and Wales respectively, they ensure that unconventional hydrocarbon operations do not harm people and/or the environment, and are responsible for issuing environmental permits.

Health and Safety Executive (HSE)

The independent regulator for the UK. In the context of unconventional hydrocarbons, HSE monitors well integrity and site safety practices.

Minerals Planning Authorities (MPAs)

Local authorities responsible for mineral planning.

Coal Authority

A non-departmental public body sponsored by DECC. It owns, on behalf of the country, the vast majority of the coal in Great Britain, as well as former coal mines.

United Kingdom Onshore Oil and Gas (UKOOG)

The representative body for UK onshore oil and gas industry including exploration and production.

About Energy Essentials

Produced and published by the Energy Institute (EI), the Energy Essentials series provides an accurate, concise, accessible explanation for a variety of topical energy sectors. The Guides are intended to promote understanding of energy topics among the general public, and are suitable for students, professionals whose work crosses over into the energy sector, or anyone with an interest in energy.

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9780852937013

ISBN 978 0 85293 701 3