CIWEM Chartered Institution of Water and Environmental Management

Shale Gas and Water 2016

An independent review of shale gas extraction in the UK and the implications for the water environment

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www.ciwem.org/shalegas

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In compiling this review CIWEM has consulted widely with its membership and technical panels, hosted a national conference on shale gas and met with the key stakeholders from the government, regulators, shale gas and water industries and civil society groups.

This report provides an update to the January 2014 report *Shale Gas and Water*.

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- Brings members from all over the world together under common policy and technical issues
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Executive Summary

Purpose

The use of water in hydraulic fracturing to unlock natural gas trapped in shale formations has brought the water-energy nexus to the fore. In 2014 CIWEM published a review of the implications for the water environment with ten recommendations for action. Although exploration has not progressed in the UK during this time, there have been considerable developments in legislation, policy and regulation.

This report provides an update for 2016, reviewing the latest publicly available evidence to assess the likely viability, scale and timing of shale gas exploitation in the UK. From consultation with experts, it then considers if an industry of any significant scale were to develop, what the implications of hydraulic fracturing of shale would be for water resources, water treatment and the water environment. In this context, the report also considers the suitability of the current and expected future regulatory requirements for mitigating the industry's potential impacts on the environment.

This report does *not* consider in detail whether shale gas can be a sustainable, bridging energy source for the UK as part of a longer-term programme of decarbonisation, nor does it assess the robustness of UK Government's wider energy policy. These issues and wider environmental issues, such as the release of fugitive emissions and induced seismicity, are examined in a separate policy position statement by CIWEM[i].

CIWEM's Position

Environmental risks of shale gas extraction

Extracting shale gas via hydraulic fracturing and directional drilling generally poses greater environmental challenges than conventional methods of gas extraction. The environmental risks include water resource requirements, the potential contamination of ground and surface waters with methane or other pollutants used in, or mobilised by the drilling and hydraulic fracturing process, the release of fugitive methane to the atmosphere, localised air pollution, landscape and visual amenity intrusion and the potential consequences of induced seismicity. A robust regulatory regime is required to mitigate risks and to improve general public confidence in what is presently a highly controversial process.

The development of shale gas in the UK

Two years on from CIWEM's initial report, little progress has been made in terms of wells drilled, and this has been largely from delays and rejections to planning applications. However we consider that this has been of benefit, as in the interim there has been time for new legislation to be developed, the industry has collaborated and developed guidelines and the regulators have produced standard rules and guidance on best available techniques to minimise environmental harm.

The UK Government has expressed a commitment to facilitate exploration for shale gas and is putting in place a regulatory regime which it hopes will provide appropriate safeguards to communities, employees and the environment, whilst at the same time avoiding obstruction to the industry to a level that would discourage interest in this exploration. Exploration involving drilling is necessary to properly understand the size of the shale gas resource and, in the event that this is sufficiently large, how economically viable gas extraction might be. Until such exploration has taken place, a reliable estimate of the likely size and nature of any subsequent production industry is extremely uncertain.

The viability of shale gas as an economically extractable fuel resource for the UK centres upon the following key issues:

- **Resource size** with the need for sufficiently large and appropriate gas-bearing shale formations to make exploration and exploitation worthwhile as a means of providing an indigenous source of gas.
- **Extraction technology** that enables extraction to be economically viable and a skilled workforce and service sector to enable the gas to be safely secured.
- **Environmental regulation** to ensure a streamlined system that does not threaten the environment nor restrict an industry from developing.
- **Public acceptance** providing a social licence to operate for the shale gas operators. Acceptance of the visual and physical disruption associated with the drilling process in particular, especially where there might be a high density of shale gas well pads.
- **Economics** of extraction and the commodity price to be sufficiently attractive to enable a profitable industry to develop.

This report looks at each of these aspects in depth and concludes that delays in the planning and permitting process remains a barrier to the quick development of an extensive industry in the UK. A greater concern may be the ability to achieve an economically attractive return in light of higher production costs and falling oil prices. Innovation in technologies for wastewater treatment is also likely to be required to bring costs down.

It is important to emphasise that despite the extensive UK media coverage of the issue of shale gas extraction in recent years and the often vociferous nature of opposition from a growing number of local pressure groups, the activity, even at this very early exploration stage, is embryonic in the UK. In addition and for various reasons which are discussed in this report, the expansion of any industry, in the event of promising exploration outcomes, will almost certainly not be quick.

It is equally important to emphasise that whilst politicians may wish to draw favourable comparisons with experiences in the United States of America (US), the observed dramatic downward pressure on wholesale gas prices experienced there is unlikely to be seen in the UK. Likewise, because of factors such as population density, associated local opposition, geology, technological advancement and a more robust regulatory regime, any industry will look quite different to that in the US and what is commonly depicted by opposition groups with very large fields of drilling pads causing widespread landscape impact. It will need to be a well-run industry, operating with a high level of transparency, suitably involving stakeholders at all levels and employing best available techniques in order to minimise disruption.

Impacts on the water environment

An understanding of the likely size of any shale gas industry, together with its geographical focus is essential in order to appreciate the impact of this activity on the water environment. However, despite the absence of this picture, we can identify the key risks and assess impacts across a likely scale. We can also recognise the priorities for information sharing and disclosure and make recommendations for where improvements in current industry and regulatory practice should be considered.

Water use

The process of extracting shale gas is carried out in stages, with water required during the drilling and hydraulic fracturing stages. When compared to the lifetime of a shale gas well, the period for water demand is quite short and focussed at the early stages of the well's development. There are a number of factors affecting the water use of an individual well and therefore estimates are wide ranging. A typical volume of water used in the hydraulic fracturing process is between 10-20 Ml per shale well over a five to seven week period.

To understand a more regional picture with multiple sites, UK research has suggested that for 1000 wells, the estimated peak demand is 2.2 Ml per day. For comparison United Utilities in the North West currently supply around 1,750 Ml per day of drinking water in a normal year. Therefore in the context of regional water supply it constitutes a small fraction of what a single water company might be asked to supply. The water industry does not for the time being appear concerned about its ability to supply a shale gas industry as a customer during the exploration stages as suggested by their Water Resource Management Plans. There are other options for supply, such as direct abstraction, should supply from a water company not be appropriate.

However should a significantly sized production industry develop, there may be local consequences in some catchments in the south east which are already water stressed. In these cases it will be up to the water companies to decide if they are able to supply the water or the relevant environmental agency if it is to be abstracted. Where water stressed catchments and shale gas licence areas coincide, operators will need to be aware of the risk that there may be reduced volumes available in the future. The likelihood of water shortages may increase and such incidences may restrict the industry's operations.

There is the potential for drilling and fracturing processes to be timed as to when volumes of water are available. Furthermore, research is ongoing into hydraulic fracturing techniques that use less water and methods to increase the proportion of flowback water that could be treated and reused directly on site. Recycling and good onsite management is important to ensure that water efficiency is addressed. Where there are multiple companies operating in a particular area, collective water supply and reuse systems could provide efficiencies.

It is therefore considered that water supply issues will be local and early engagement by shale gas companies with the environment agency and water companies is essential to establish the nature of any risks and manage them accordingly. CIWEM considers companies should continue to work to improve the accuracy of their water consumption and production estimates and communicate these with water companies.

Water pollution

A frequently expressed public concern associated with shale gas operations is that contamination of groundwater could occur. This may result from a catastrophic failure or loss of integrity of the wellbore, or if methane or contaminants can travel from the target fracture through subsurface pathways to an aquifer. There is also the potential for pollution of the local land and water environment if the returned water from the hydraulic fracturing process is not appropriately contained, managed, and treated prior to eventual disposal. Any material spilt on or applied to the ground has the potential to reach the water table.

Risks to groundwater quality from mobilisation of methane and other contaminants, are generally considered to be low where target shales exist at considerable depths below aquifers and contaminants would be required to migrate many hundreds of metres between source rock and sensitive overlying groundwater. New regulations restrict hydraulic fracturing to below 1200 metres in source protection zone 1 to protect public drinking water supply. This is also the case in National Parks, the Broads, Areas of Outstanding Natural Beauty and World Heritage sites. Elsewhere the Environment Agency has stated it will object to shale gas extraction infrastructure or activity where the activity would have an unacceptable effect on groundwater, or if it is close to sensitive receptors it will adopt the precautionary principle through planning or permitting controls.

Where the source rocks are shallower and regulations permit, the risk of contamination of water resources and the environment is to be thoroughly assessed during the planning and permitting stages. Current regulation requires operators to produce a hydrogeological assessment conducted by a specialist expert at the planning and permitting stages and when submitting an intention to drill a borehole. This will evaluate any risks to groundwater from substance used or released from drilling and well stimulation activities.

Risks to groundwater from wellbore failure must continue to be seriously considered by all appropriate regulators and construction closely monitored to ensure that best practice is followed. There needs to be high clarity and transparency about the methods used to continually verify well integrity throughout the exploration, production and decommissioning phases, with all permit-specified data placed rapidly in the public domain, and interpreted by the regulator. Rigorous well testing can help to identify any potential problems that can then be repaired before operations re-commence.

CIWEM considers the most significant risk relates to the management of flowback and produced water. Any negligence associated with storage, transportation and operations resulting in spills represent the greatest threats to surface water, as well as to groundwater. Good pollution prevention practice will be essential during exploratory phase as well as the construction, production and decommissioning phases. These can be effectively managed through robust best practice and there is no reason why this should not be achievable. Close monitoring and scrutiny by regulators, allied to strict enforcement, will continue to be essential to ensure that the industry acts in an appropriately responsible manner. The Environment Agency also expects operators to demonstrate best available techniques to protect groundwater in their permit applications.

In order to establish the current condition of the water environment and successfully identify where contamination may have occurred, either as a result of shale gas-related activities or others, good baseline data are required. Experience from the US and Australia shows that without good baseline data, it is hard to scientifically establish a cause of contamination and this fosters conjecture, commonly leading to a polarised discussion lacking in robust evidence. It is important that before shale gas activities commence, baseline data for appropriate contaminants are obtained for soil, ground and surface waters that are potentially at risk.

In the early phases of development of UK-relevant techniques it will be reasonable for the regulators to require intensive monitoring data from the operators to verify the safety and integrity of the techniques. Data quality specifications, laboratory inter-calibration and quality assurance systems will be essential to establish trust. It should be expected that, once the operators have demonstrated the suitability and low risk of pollution from fracking techniques, the level of monitoring data may safely be reduced.

Water treatment

Flowback and produced water will need to be treated before being returned to the environment. The technologies required will depend on the contaminants present and these in turn will reflect the local geology and the composition of the fracturing fluid. Specialist commercial treatment facilities will need to be used where the wastewater is not of a composition that is acceptable at public wastewater treatment plant permits.

Treatment and reuse of produced and flowback water is an area where technology is rapidly developing and may enable on-site treatment by the time an industry is in any way mature in the UK. Otherwise, a supply-chain of specialist treatment facilities will need to develop to meet market need where this cannot already be provided by larger public and industrial wastewater treatment sites.

Reuse of flow back and produced water arguably represents the most sustainable process in terms of water resource use and also reduces the risks associated with transporting waste. Reusing and recycling of produced waters also acts to reduce the volumes of water and waste ultimately requiring final treatment and disposal. The re-injection of flowback and produced water must be carefully regulated to ensure that there are no cases of induced seismicity. The final guidance on re-injection for reuse and disposal is expected in early 2016.

Public acceptance

CIWEM considers that the importance of clear, open stakeholder engagement from all parties cannot be overstated with an issue which is subject to such passionate debate. Water lies close to the majority of concerns expressed by stakeholders in this discussion and it is important that all parties properly understand the impacts of the current exploration industry as well as those that are likely to require management were a moderately sized extractive industry to develop.

Given the proximity of any industry to local populations in the UK and the ability of opposition groups to mobilise against risks they perceive to be unacceptable, any UK shale gas industry will need to be an exemplar of good practice, alongside those bodies which govern and regulate it. It is important that the public are reassured that regulation is fit for purpose and that transparency is displayed at all levels in order to establish trust.

Finally, in updating this report we have been pleased to observe that the UK is moving in the right direction with regulations being developed that protect the water environment and several stakeholders working collaboratively to establish baseline studies, guidance and best practice. Many of the ten recommendations we first set out have now been implemented or are in train. However, this does not preclude the need for continual scrutiny and diligence by all parties concerned and further research and practice in the areas highlighted below.

Progress since CIWEM's 2014 recommendations

	Recommendations	Progress
1	**Government departments and agencies should actively promote informed understanding among stakeholders using clear scientific evidence, transparency and consistent messages, across a range of media and forums. Government Ministers should ensure that their messages on shale gas are consistent with those of the departments.**	The relevant Government departments and agencies have made considerable progress to improve public understanding. DECC and the regulators have produced a wealth of material and guidance to this aim. However there is still some inflammatory language being used by some senior Parliamentarians. A series of Government 'u turn' announcements on protected areas has undermined some public trust, although generally the outcome has been welcomed as improving environmental protection. The change to allow the intervention of Secretaries of State in determining planning appeals is likely to cause deepened public concern with the erosion of localism.
2	**The industry should ensure it complies with the UK Onshore Oil and Gas (UKOOG) community engagement charter so that the public are involved within the planning process with adequate notice and information. The production of guidance for local communities on what they can expect and where they can and cannot influence would be helpful.**	The industry, through UKOOG, has committed to conducting early stage environmental risk assessments to be discussed with local communities and Environmental Impact Assessments associated with sites that include hydraulic fracturing. These commitments have been put in place for planning applications submitted for three sites in Lancashire and North Yorkshire. Yet public opposition in these areas remains strong. Building public trust is still a key issue for the industry to ensure it has a social licence to operate. UKOOG has also published further guidelines for the industry on addressing public health and

		establishing environmental baselines which will be helpful in building the integrity of the industry.
3	**Further collaboration between the agencies involved in advising and regulating the industry is required. As regulation is developed for the appraisal and production phases, a rationalised and integrated system of risk assessment should be included to avoid confusion, increase public engagement and reduce delays.**	The Oil and Gas Authority (OGA) has been set up as an executive agency of DECC, although regulatory responsibility still sits between a number of agencies. It is possibly too early to assess the work of the OGA and how it will work with the others involved in regulation. The Environment Agency is working on sector guidance for permitting and best available techniques (BAT) for the industry where these are available. It has also established standard rules permits to reduce delays. The industry has produced draft guidelines on Environmental Risk Assessment and Environmental Impact Assessment, which it expects to complete in early 2016. These should be independently scrutinised to ensure that they adequately protect health and the environment.
4	**CIWEM believes water and sewerage companies should become statutory consultees in the shale gas planning process regardless of whether they continue to provide and treat water for the industry. They must be engaged with early and provided with the right information to meet their duties.**	It is welcome that this has been recognised and progressed through the *Infrastructure Act 2015* and implemented in *The Town and Country Planning (Development Management Procedure (England) Order 2015*. It will now be for shale gas and water companies to build relationships and make sure that this is put into practice, particularly as the industry moves into the production phase.
5	**The importance of baseline monitoring cannot be overstated. Regulators must ensure that an environmental baseline is fully established before any commencement of drilling activity and this should include both deep and shallow aquifers for radio-nuclides and other contaminants. Full details of the environmental monitoring programme should be disclosed.**	The British Geological Survey (BGS) has completed a national baseline methane survey and is undertaking comprehensive baseline monitoring at two proposed sites in Lancashire and one in Yorkshire. It is welcome that this is independent from the industry and the findings should be used to update baseline monitoring guidelines and used at all sites in the future. Draft Environment Agency guidelines set out that a site condition report is required before commencement of operations.

		UKOOG published baseline monitoring guidance for soil, air and water before and during operations in 2015 with which all of its Members must comply.
6	**The long-term monitoring of relative conditions to the environmental baseline in the vicinity of the well and nearby receptors throughout the lifetime of the well will be important to detect any contaminants. In developing production guidance, parameters on the frequency, locations and time scale of measurements should be included.**	The *Infrastructure Act 2015* now requires appropriate arrangements for the monitoring of emissions of methane into the air for the duration of the permit. The Environment Agency has produced draft guidance for operational monitoring on a wide range of aspects. It considers it best practice to undertake groundwater monitoring even if it not required by a permit. The BGS comprehensive baseline study should be used as a strong evidence base against which to any future changes in environmental condition can be assessed and future monitoring programmes designed.
7	**The protection of groundwater must be made a priority and the environmental regulator should continue to adopt the precautionary principle where there is insufficient certainty to protect groundwater. Operators should provide the environmental regulator with a detailed risk assessment to examine the relationship between the shale and the aquifer including a thorough evaluation of geological and hydrogeological setting.**	The *Infrastructure Act 2015* prohibits hydraulic fracturing anywhere at a depth of less than 1000 metres. New provisions set out in the *Onshore Hydraulic Fracturing (Protected Areas) Regulations 2015* restrict hydraulic fracturing to take place below 1200metres in Source Protection Zone (SPZ) 1. This should provide a reasonable buffer to protect the groundwater from contamination by methane and other contaminants, although a more effective requirement may be for the operator to demonstrate that there is no connectivity. It is welcome that the Environment Agency now requires the completion of a hydrogeological assessment to be undertaken by a suitably qualified person in its latest draft guidance. Outside of the restricted areas the risk of contamination from the loss of well integrity still requires consideration. Best available techniques will need to be applied by operators to ensure returned waters are appropriately contained, managed, and treated prior to eventual disposal. CIWEM considers

		mismanagement is one of the greatest risks for contamination of the environment.
8	**Further research is needed into hydraulic fracturing with lower quality waters and also waterless techniques to minimise water use and thus requiring less subsequent treatment.**	The service industry continues to work on lower water quality solutions internationally. The UK should identify what it can learn from this, particularly as the industry enters the production phase.
9	**Research and development is needed in water treatment and decontamination technologies that exhibit reduced energy consumption, as well as into onsite and mobile treatment solutions that reduce the risks of transporting waste.**	The Natural Environment Research Council (NERC) in the UK and the United States National Science Federation (NSF) are jointly looking at scientific and technological innovation to improve understanding and mitigate potential environmental impacts. There is also work being undertaken by the EU Commission Joint Research Centre in this area. CIWEM, UKOOG, WaterUK and British Water have established an initiative to bring together key stakeholders to consider the whole life management of water issues, including mobile treatment solutions and water sourcing. Most of these initiatives are in their infancy and there is still much to learn from abroad and progress.
10	**The reuse of hydraulic fracturing fluid on site is the preferred option of the industry and the regulator. Given that there is common ground between the industry and regulator, they should work closely together to identify optimum solutions.**	The environmental regulators have been looking to develop best available techniques for the management of flowback fluid and re-injection. The Environment Agency's final sector guidance to be published in early 2016 is likely to suggest that the reinjection of flowback and produced water will be allowed for the purposes of re-fracture. A groundwater permit and in some cases a radioactive substances permit will be required. Re-injection for disposal may be allowed in certain circumstances. CIWEM considers the risks from contamination and induced seismicity must be adequately assessed for any re-injection activity through the groundwater permit and hydrogeological assessment.

Abbreviations

BAT	Best Available Techniques
BGS	British Geological Survey
CAMS	Catchment Abstraction Management Strategy
CCS	Carbon capture and storage
DCLG	Department for Communities and Local Government
DEFRA	Department for Environment, Food and Rural Affairs
DECC	Department for Energy and Climate Change
EA	Environment Agency
EIA	Environmental Impact Assessment
EPR	Environmental Permitting Regulations
ERA	Environmental Risk Assessment
GHG	Greenhouse Gas
GIP	Gas in place
HFP	Hydraulic Fracturing Programme
HSE	Health and Safety Executive
LNG	Liquefied natural gas
NIEA	Northern Ireland Environment Agency
NORM	Naturally occurring radioactive materials
NRW	Natural Resources Wales
OGA	Oil and Gas Authority
OUGO	Office of Unconventional Oil and Gas
PEDL	Petroleum Exploration and Development Licence
SEPA	Scottish Environmental Protection Agency
TRR	Technically Recoverable Resources
UKOG	UK Oil and Gas
UKOOG	UK Onshore Oil and Gas
WFD	Water Framework Directive
WRMP	Water Resource Management Plan

1. Background

The role of natural gas in the UK's energy mix

In the UK natural gas provides 80 per cent of domestic, commercial and industrial heating and the majority of homes use gas for cooking[ii]. Gas is used as a raw material in everyday items, including plastics and adhesives, is a key feedstock to the chemicals industry and is also used to make nitrogen-based fertilisers, which are spread on 75 per cent of UK farmland to help grow food[iii].

Gas also forms an integral part of the electricity generation mix, playing a role in maintaining energy security, affordability and being 'cleaner' than coal for the same energy output. Since the early 1990s, investment in gas electricity generation infrastructure has been an important component of the energy sector, accounting for nearly 70 per cent of new capacity coming online between 2000 and 2011.

Modelling by the Department for Energy and Climate Change (DECC) suggests that under a diversified energy mix scenario, up to 26 GW of new plant could be required by 2030, in part to replace older coal, gas and nuclear plant as it retires from the system[iv]. The precise role will depend on how the market develops and how other technologies are deployed. This would create an estimated total capacity of 37 GW of Combined Cycle Gas Turbines (CCGT) which would provide around 30 per cent of UK's total energy capacity (Figure 1.1).

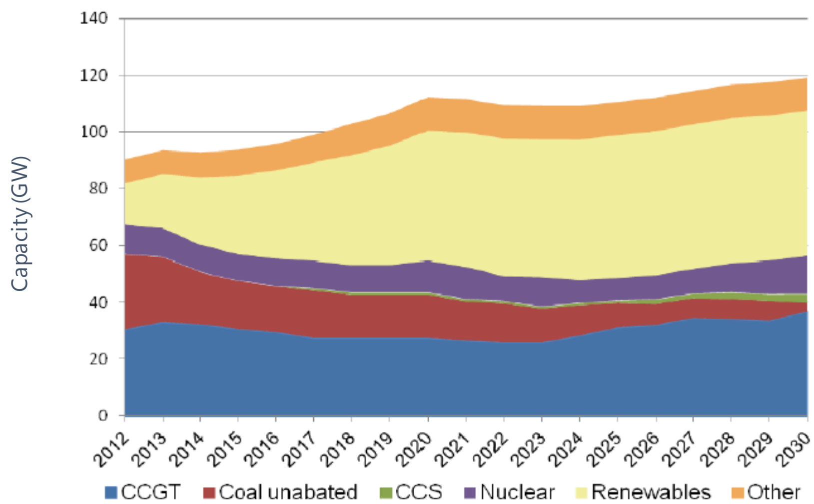

Figure 1.1 Estimated Total Capacity 2012-2030 under diversified energy mix scenario. Gas shown in blue.

With continued demand for gas and as wholesale imported gas prices are speculated to rise, the potential to extract domestic gas is particularly attractive. The Government's desire to maximise indigenous gas production will allow the UK to reduce its reliance on energy imports which are otherwise expected to increase from 50 per cent to 76 per cent by 2030, and provide considerable tax benefits to the Treasury with minerals being the property of the Crown.

The shale gas revolution in the US has sparked interest around the world. Shale gas is 'natural gas' that is found trapped within shale formations underground which can be accessed by hydraulic fracturing. The UK Government has expressed a commitment to facilitate exploration for shale gas and is putting in place a regulatory regime which it hopes will provide appropriate safeguards to communities, employees and the environment.

DECC note that the pace of development of a shale gas industry in the UK will be slower than has been seen in the US: "*If exploration is successful, early production is likely to be seen in the second half of this decade, but any substantial contribution to the UK's gas supply is unlikely until further into the 2020s*"[v]. In its most 'shale friendly' scenario, the National Grid predicts that by 2025 shale could be supplying 15-20 per cent of the UK's gas.

In terms of lifecycle greenhouse gas emissions in electricity production, natural gas has the lowest intensity of all the fossil fuels. As such it is being touted as a bridging fuel that can be used whilst renewable energy sources are developed to achieve grid parity. A concern with putting the emphasis on the development of a shale gas industry as a bridging fuel is its potential to distract from decarbonising the electricity sector. The lead-in time for shale gas may reduce its effectiveness as a bridging fuel, whereas if renewables were scaled up they could be achieving grid parity far sooner. CIWEM considers developing renewable energy sources and delivering energy efficiency must also be completed in parallel to the development of any shale gas industry.

The independent Committee on Climate Change has considered the role of shale gas in the UK[vi]. It concluded that domestic production can be consistent with meeting UK carbon budgets to 2027, but only if production is regulated to ensure that fugitive methane emissions are low and it is accompanied by a strong commitment to reduce all greenhouse gas emissions, for example by setting a power sector decarbonisation target. It has recently published its advice for the fifth carbon budget 2028-2032[vii], in which emissions are limited to 57 per cent less than 1990 levels[i]. Beyond 2032 it has not yet provided analysis, yet this is the main timeframe when the industry would be expected to be in production. In March 2016 it is expected to publish a report assessing the compatibility of UK onshore petroleum extraction with carbon budgets and the 2050 target, which could have significant implications for the industry.

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[i] Actual emissions would need to fall by 61 per cent to meet this budget, the CCC says. The difference is a result of emissions accounting rules, with part of the UK's emissions covered by the EU Emissions Trading System.

Extraction of unconventional gas

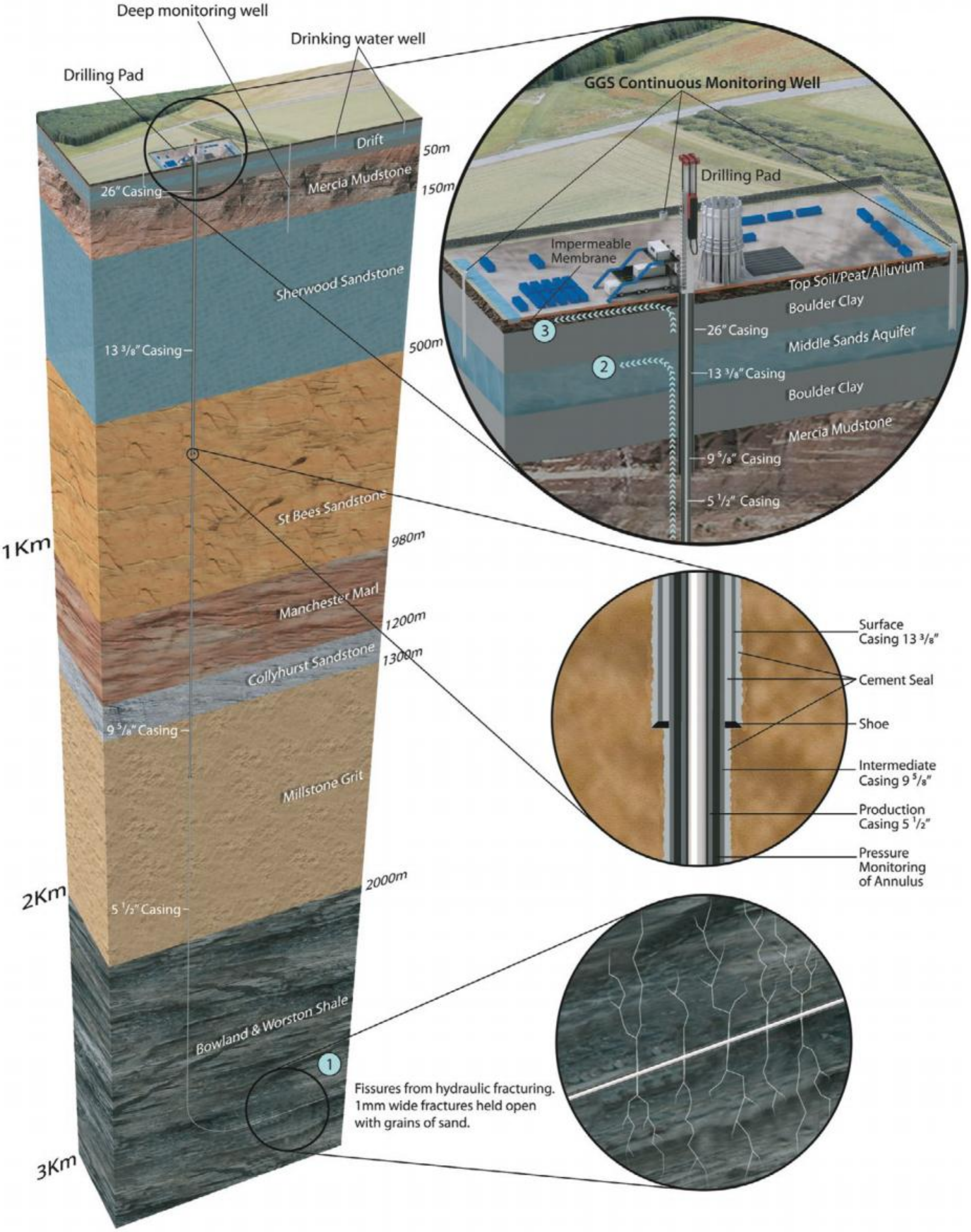


Figure 1.2 Shale gas, hydraulic fracturing and environmental monitoring for north west England via GGS Ltd

The UK has a long history in the production of oil and gas from 'conventional' hydrocarbons found in both onshore and offshore fields. This is where hydrocarbons are found in reservoirs and can be accessed by drilling an oil well. 'Unconventional' hydrocarbons are termed as such on the basis of their relative difficultly of extraction. Unconventional gases include shale gas, coal bed methane and tight gas and exploration for the first two of these is currently underway in the UK. These sources are now being developed as technological breakthroughs have allowed them to be more readily accessed and therefore more commercially viable.

Unconventional hydrocarbons are found under conditions that do not allow them to flow and be easily captured. Shale gas is mostly composed of methane or 'natural gas' that is trapped within the pores of shale rock. The extraction of this shale gas at economically viable flow rates relies on the use of two technologies; horizontal drilling and hydraulic fracturing (figure 1.2).

As shale gas deposits are typically deeper than conventional reservoirs and coal bed methane sources, they require deeper wells and the use of horizontal wells to maximise the amount of shale area that can be fractured. Horizontal drilling allows this to take place. To enable the gas to flow from the shale to the well it has to be systematically fractured using high pressurised fluids to create fractures in the rock. Chemicals and proppants (typically sand) are added to the fluid, the proppant holds hold open fissures in the rock whilst the chemicals ensure that is moved into and then kept in place. This encourages the oil or gas to flow to the well. This is hydraulic fracturing, commonly referred to as 'fracking'.

Horizontal wells are fractured in stages with a lateral drilled, perforated and then fractured; a mechanical plug is put in place to stop the gas from flowing back up the well whilst the next section is perforated and fractured. This process continues until the whole lateral has been fractured, the plugs are then drilled through to allow the fracturing fluid and gas to flow up the well.

Hydraulic fracturing is a process not solely associated with extracting gas from shale and is also routinely used in conventional oil and gas fields and hydrothermal wells to extract hydrocarbons. It is also occasionally used in water wells to enhance well yield and in geothermal energy production. Many of the environmental risks that are attributed to hydraulic fracturing may be nothing to do with the fracturing process itself and rather result from poor well design and construction or poor handling of chemicals or returned waters at the surface.

What makes hydraulic fracturing in shale gas extraction different from other hydrocarbon extraction techniques is that it is on a greater scale; the wells are often drilled deeper than conventional wells and a greater number of wells (including lateral wells) are needed to access the resource. Shale also requires higher volumes of water and chemicals and higher water pressures due to the depth of the well and because there are very few natural fissures in the rock. This can present engineering challenges.

The shale gas industry in the UK has been subject to many delays. A moratorium was put in place following minor earthquakes near a site in Blackpool. Since this was lifted in December 2012 there have been further delays to the industry through local opposition to planning applications showing the delicacy of the situation. More licenses were announced in the 14th licencing round launched in July 2014, which attracted almost 100 applications for over 295

Ordnance Survey Blocks. In August 2015, 27 onshore blocks were formally offered to companies with a further 132 blocks being subject to detailed assessment and consultation under the *Habitats Regulations 2010*. The consultation concluded that no European sites would be adversely affected and the Oil and Gas Authority (OGA) offered licences for all 159 blocks. For 75 of these blocks, the licence will contain a condition that prohibits all or specific activities in parts of the block[viii]. The companies with these licenses will now progress planning and permitting applications to begin exploration.

2. Viability of commercial shale gas development in the UK

This chapter discusses the viability of shale gas as an economically extractable fuel resource for the UK and centres upon the issues illustrated in this flowchart:

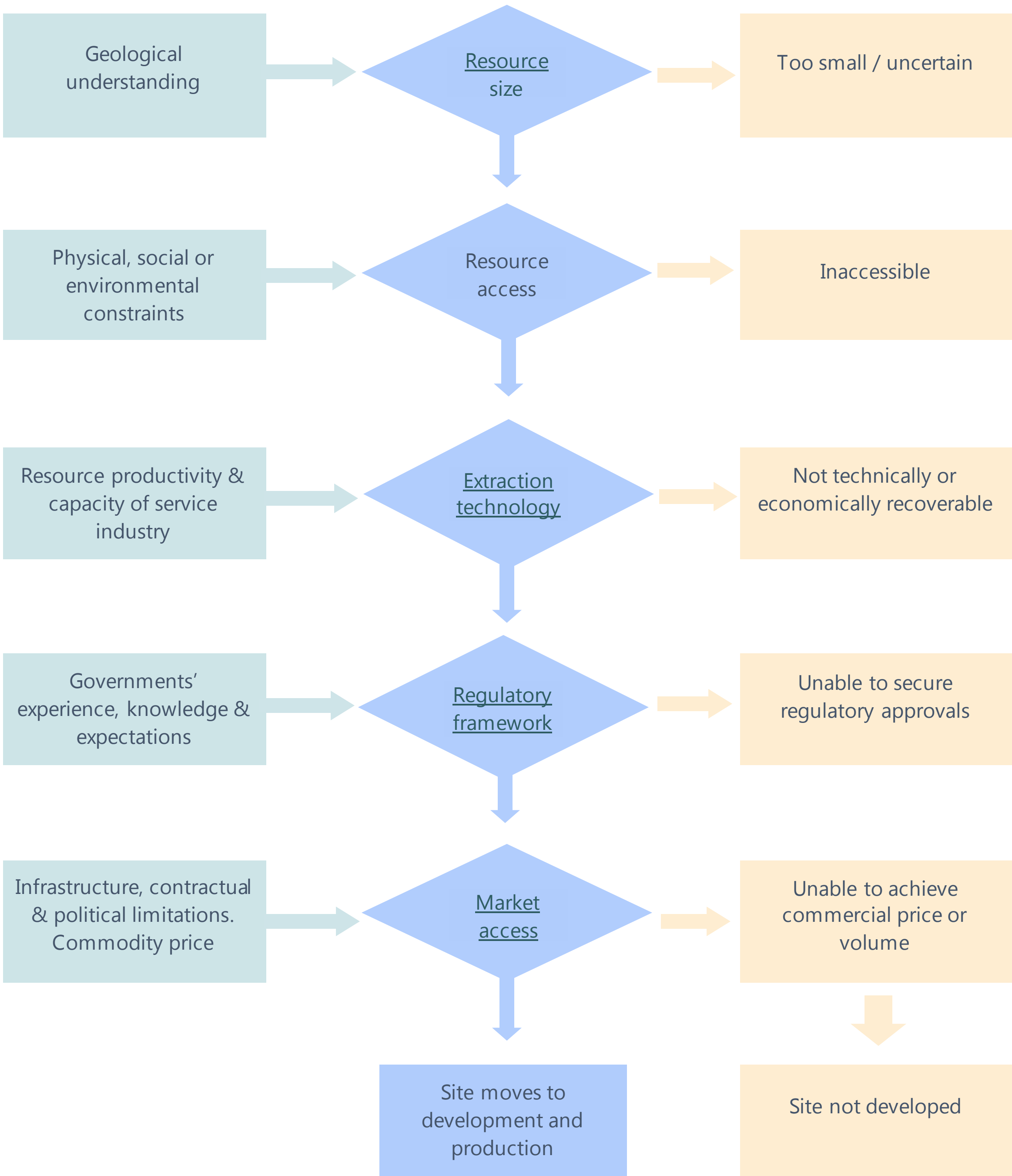


Figure 2.1 Flowchart illustrating factors determining the viability of natural gas developments[ix]

Resource size

Figure 2.2 shows areas of the UK which feature geology with potential for rich resources of shale gas. Yet the existence of appropriate geology does not mean that it will necessarily be suitable as a source of shale gas for extraction. To establish a realistic estimate of the *reserve* volume, exploratory drilling and testing is required.

Key

- Kimmeridge Clay outcrop
- Oxford Clay outcrop
- Lias Outcrop
- Namurian (Millstone Grit) outcrop
- Cambrian including Tremadoc outcrop
- Conventional wells which flowed gas
- Conventional wells drilled
- Jurassic Lias Subcrop
- Namurian Subcrop

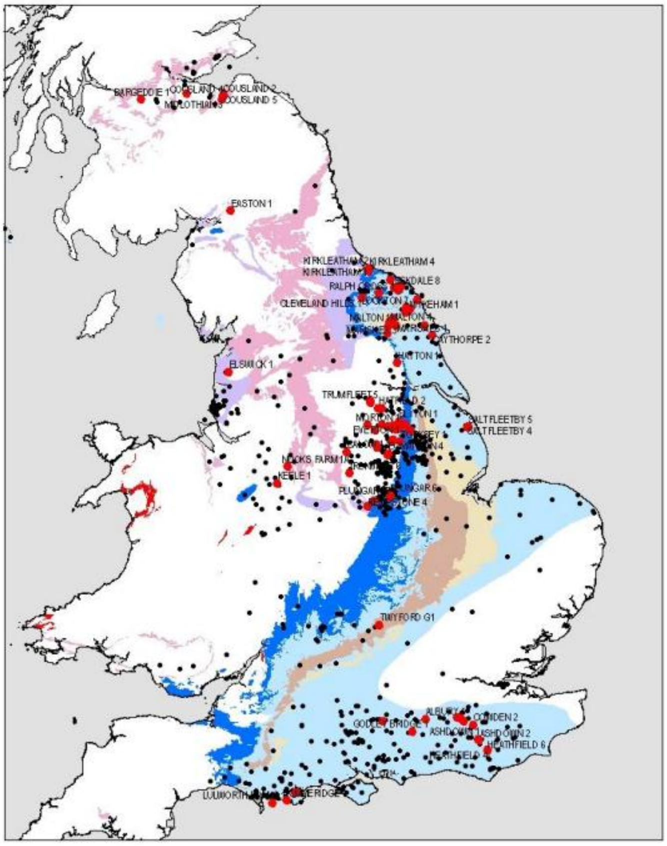


Figure 2.2 Main areas of prospective UK Shale formations[x].

NOTE: Prospective formations may be found below other formations at depth. Further information on each formation can be found in the source document.

Some key terminology:

- Shale gas *resources* are the estimated total volume of gas (gas-in-place (GIP)).
- Potentially or Technically Recoverable Resources (TRR) are those that are estimated as extractable from the total resource.
- Shale gas *reserves* are the fraction of the TRR that is deemed to be commercially recoverable using today's technologies[xi].
- A resource *play* is an accumulation of hydrocarbons known to exist over a large area, believed to have a lower geological and/or commercial development risk.

In 2013 DECC commissioned the British Geological Survey (BGS) to undertake a detailed GIP analysis for part of central Britain in an area underlain by the Bowland Shale which extends across a significant area of England from the Midlands northwards[xii]. The Bowland Shale is believed to be the rock type with the greatest potential for shale gas in the UK as it occurs at both depth and at outcrop and it is known from previous studies and investigations to be an excellent hydrocarbon source rock.

The study involved integrating 15,000 miles of seismic data with outcrop and fault mapping, well data, historical and newly-commissioned laboratory studies to identify the potential volumes of shale gas. The central estimate of GIP was 37.6 trillion cubic metres. Using similar recovery factors to the US (8-29 per cent) gives a TRR estimate between 1.8 – 13 trillion cubic metres (UK annual gas consumption is 77 billion cubic metres)[xiii]. These studies are not able to accurately to predict reserves (i.e. that will be technically and commercially produced) and exploratory drilling will be required. In order to do this shale gas operators need to apply for and receive a license from DECC.

Figure 2.3 shows the outcome of the latest licensing round in 2015. Whilst the licensing round has increased the area available to "search and bore for and get" hydrocarbons, the licences do not in their own right, confer on the licensee any consent, permission or authorisation to carry out development activity.

Key

- Major towns and cities
- Blocks offered under 14th licensing round
- British National Grid (10km)
- British National Grid (100km)
- Current Licensed Blocks
- Jurassic Weald Basin
- Bowland-Hodder shale

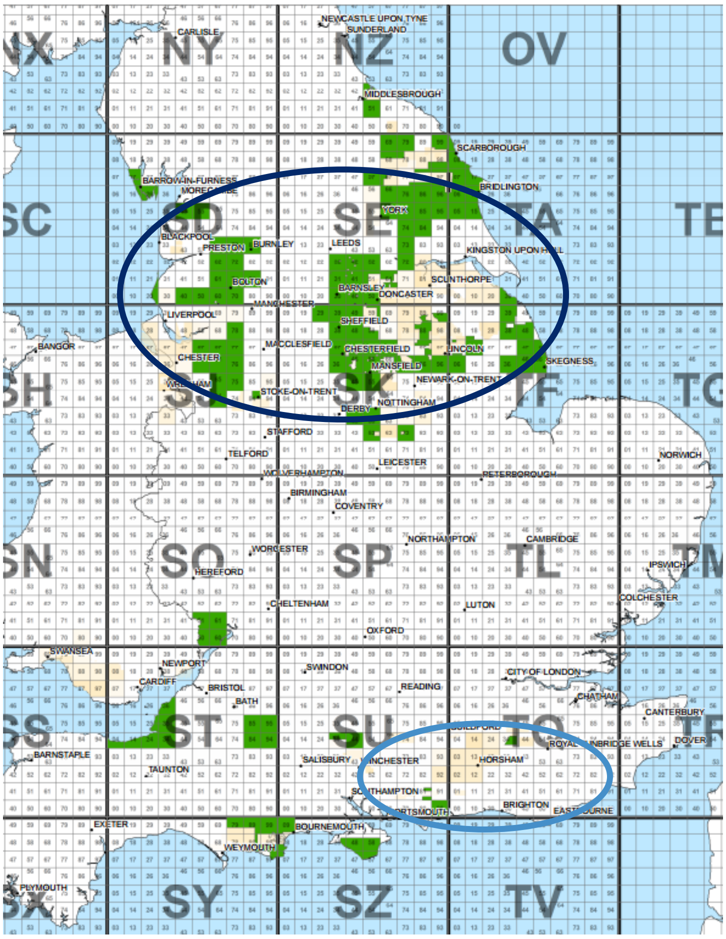


Figure 2.3. OGA. 14th onshore oil and gas licencing round 2015.

NOTE: Licences do not distinguish between shale gas and other forms of hydrocarbons. Comparing these to the geological maps may indicate which are in areas of shale gas potential.

Similar GIP studies have been carried out by the BGS in association with DECC. Completed shale resource estimates for several areas in the UK in 2014:

- Midland valley of Scotland[xiv] (central estimate for the resource being 80.3 tcf)
- Jurassic shale of the Weald Basin (shale oil rather than gas)
- Wales[xv]

In Northern Ireland a new Strategic Planning Policy Statement[xvi] incorporates a presumption against unconventional hydrocarbon extraction until it believes it can be proven to be environmentally safe.

In the experience of the US, resource estimates increased by 40 per cent over the two years between 2007 and 2009[xvii]. However elsewhere in areas of Norway, Poland, China and South Africa resource estimates were revised lower in 2013 than their 2011 estimates[xviii]. It may require a period of around two years of exploratory drilling in order to establish the viability of shale gas in the UK[xix]. Until that point, very low levels of certainty can realistically be attached to claims on either side of the discussion. This uncertainty is of greater relevance in the case of unconventional oil and gas than for more conventional sources, which are easier to assess and predict.

Extraction technology

The existence of an extensive shale gas resource is only part of the equation; critical is whether the technology exists to make it economically viable to extract and sell. The UK has both areas of deep shales and those that come to the surface. The Bowland Shale formation in Lancashire for example, exists at depths of up to 5km below the surface[xx] compared to the often shallower and thinner plays found in the US. This will require deeper wells and more lateral drilling to access the resource, which may make the process more challenging and expensive, but could also reward operators who invest in technological development by maximising the amount of shale gas liberated from the well.

Although there has been minimal activity within Europe, in the US, completion and drilling techniques are well established and drilling efficiencies continue to improve even as laterals extend to increasing lengths. Operations in the US typically feature laterals from 300m to more than 1500m. Some areas of the Bakken shale (US and Canada) have laterals up to 3600m in length as operators attempt to contact as much of the reservoir as possible from a single wellbore. The advancement already shown, and what may develop in the future, will be of benefit to the industry as more gas can be extracted from the same well and the same entry point, minimising surface disruption and social limitations.

As lateral lengths have increased, they have had to be fractured in stages to maintain a sufficient downhole pressure (Figure 2.4). The number of stages has increased in the US from 20-30 stages per well to up to 90 or more, with the average in the area of 30-50 stages across the different plays[xxi]. Completion techniques have also advanced to adapt to higher pressure and temperature fracturing conditions. Some plays in the US have begun to implement pad drilling, the drilling of several wells from a single location rather than a single well per pad. Pad drilling can reduce environmental footprint, streamline logistics and improved operational efficiencies. However the industry claims there is still considerable scope to improve recovery factors and reduce overall costs[xxii].

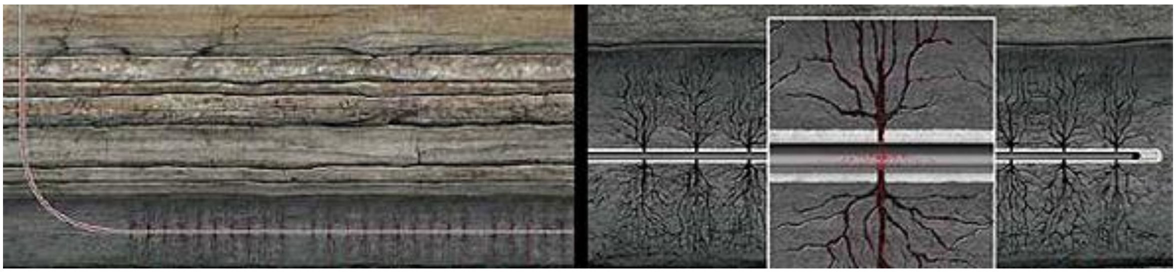


Figure 2.4 Stages of a hydraulically fractured lateral well

The trade body UK Onshore Oil and Gas (UKOOG) notes that the UK suffers from a lack of a shale gas supply chain. For example one recent rig count identified 1900 land rigs and 500 fracturing crews in the US compared with 77 rigs and 10 fracturing crews in the whole of Europe[xxiii]. Professional services firm EY[xxiv] has identified a lack of oilfield service sector capacity, equipment and appropriately skilled labour as obstacles to rapid shale gas development in Europe. It notes that the service level intensity is higher for unconventional oil and gas than for conventional hydrocarbons, and that in the US the sector has developed significantly to provide skills and services for shale gas and is now looking to export expertise internationally.

The UK has the benefit of a historically strong service industry, having a small onshore industry and an extensive offshore industry associated with North Sea oil and gas. Although this is in conventional sources, the sector has also been required to innovate given the challenges of working in a hostile environment, thus it is potentially well placed to expand into unconventional oil and gas should the economic drivers be sufficiently attractive. The UK does at least already have access to sophisticated gas distribution and transmission systems.

Environmental regulation

The conventional oil and gas industry is mature in the UK and is already tightly regulated both onshore and offshore. Unconventional oil and gas exploration and exploitation is regulated by appropriate sections of DECC, the Environment Agency (EA) and the Health and Safety Executive (HSE). In April 2015 certain functions passed from DECC to the Oil and Gas Authority (OGA) a newly created Executive Agency of DECC and independent regulator. Shale gas is also subject to planning requirements through the Department for Communities and Local Government (DCLG) and local authorities (figure 2.5). Elsewhere in the UK the Scottish Environmental Protection Agency (SEPA), Natural Resources Wales (NRW) and the Northern Ireland Environment Agency (NIEA) fulfil the role of the environmental regulator. Northern Ireland also has a separate Health and Safety Executive. These bodies also ensure compliance with European Directives and national legislation. DECC has produced roadmaps for onshore exploration in each of the UK nations to clarify the regulatory process[xxv].

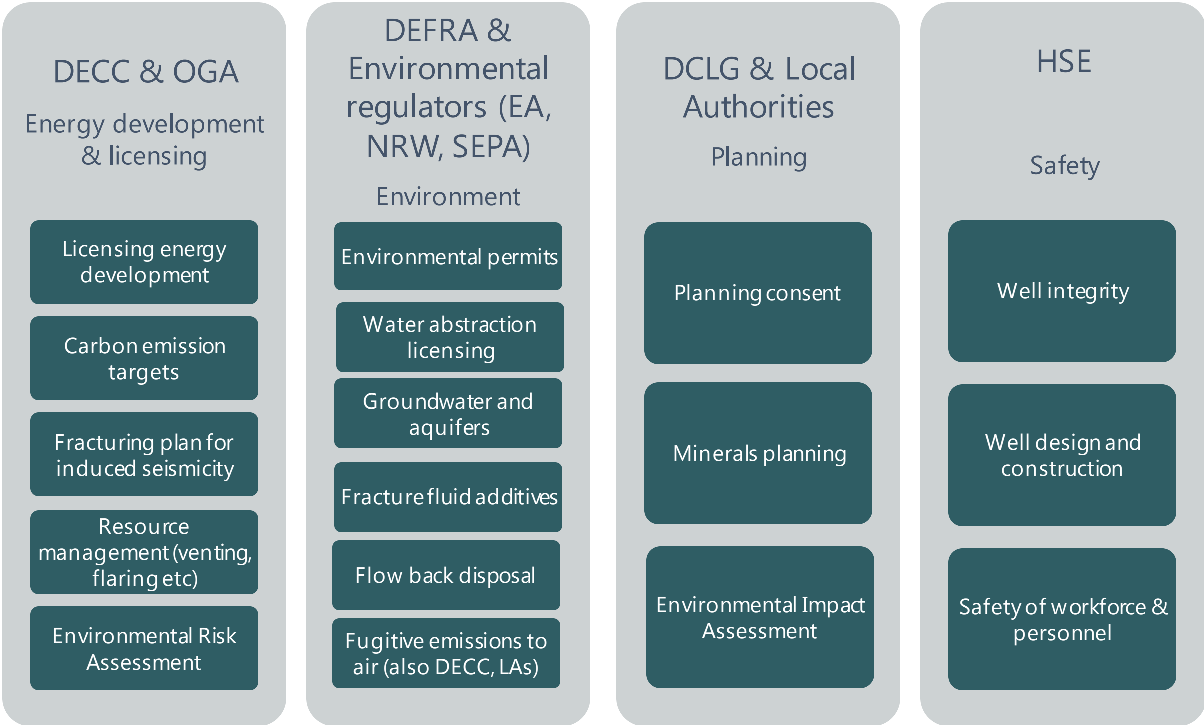


Figure 2.5 Regulatory bodies and their responsibilities in the UK shale gas industry

NOTE: There is some overlap of roles and the bodies will have to work together within this framework to ensure local scrutiny and engagement

Much of the guidance that has already been produced is for the exploration stage only and this is reflective of the infancy of the industry. The Environment Agency is consulting on sector guidance for the onshore industry until early 2016, which will cover permit requirements and best available techniques (BAT). As it is developed, regulation will need to distinguish between the different impacts associated with exploration and that of production as there will be different requirements for the control, monitoring and local issues for whether there are one or two wells or several hundred.

The *Infrastructure Act 2015* placed additional safeguards in England and Wales such as that hydraulic fracturing should not take place at a depth below the ground surface of less than 1000 metres, monitoring of methane in groundwater should be undertaken for 12 months before operations begin and hydraulic fracturing should not take place in protected groundwater source areas or other protected areas[xxvi]. For the full list of new conditions and requirements see Appendix 1 and the detailed discussion in Chapter 3.

Application process

Figure 2.6 overleaf illustrates the steps that an operator must go through to be able to explore for shale gas. Initially, for a company to commence drilling, a Petroleum Exploration and Development Licence (PEDL) must be obtained from DECC[xxvii]. These licences are issued on a competitive basis of licensing rounds and grant exclusive rights to explore, drill and produce hydrocarbons within a small defined area subject to appropriate licences and permissions.

An Environmental Risk Assessment (ERA) is required by DECC at the pre-planning stage for each site for hydraulic fracturing, which will be used to ensure that any potential risks covering the full cycle of operations are identified and acted on. DECC requires compilation of an ERA as a matter of good practice and it should include the participation of stakeholders including local communities.

Shale gas operators must then obtain planning permission from the relevant Mineral Planning Authority in order to conduct the surface activities associated with exploration and production. Mineral Planning Authorities will have their own Mineral Local Plans under the National Planning Policy Framework which will be permissive, but will detail any restrictions with regards to surface or groundwater resources or any impact on designated habitats[xxviii].

Operators are encouraged to undertake pre-application consultation with the local Minerals Planning Authority and stakeholders, which may suggest through screening that an Environmental Impact Assessment (EIA) is necessary. The industry has voluntarily agreed to undertake an EIA for all sites that involve hydraulic fracturing and these should be submitted to the Mineral Planning Authority as part of the planning application process. UKOOG has published guidelines for addressing public health in EIAs. Where the MPA believes there may be a significant impact on the health and wellbeing of the local population it may consult the Director of Public Health to undertake a Health Impact Assessment. The MPA then advertises and consults on the finalised planning application and environmental statement. The planning application will then be approved or rejected with the possibility for an appeals process.

Operators must serve a notice to the Environment Agency under Section 199 of the *Water Resources Act 1991* to "*construct… a boring for the purposes of searching for or extracting minerals*". Shale gas operators may also need to apply for environmental permits, with most falling under the *Environmental Permitting Regulations 2010* (EPR), to allow drilling to take place[xxix]. The EA's draft technical guidance[xxx] clarifies which environmental regulations apply to the onshore oil and gas exploration sector and what operators need to do to comply with those regulations.

Environmental permits may be required for:

- A groundwater activity – unless the regulator is satisfied there is no risk of inputs to groundwater
- A mining waste activity – likely to apply in all circumstances
- An installation under the Industrial Emissions Directive – when it is intended to flare more than ten tonnes of waste gas per day
- A radioactive substances activity – likely to apply in all circumstances where oil or gas is produced
- A water discharge activity – if surface water run-off becomes polluted, for example, due to a spill of diesel or flowback fluid
- A groundwater investigation consent – to cover drilling and test pumping where there is the potential to abstract more than $20m^3$/day
- A water abstraction licence – if it is planned to abstract more than $20m^3$/day rather than purchasing water from a public water supply utility company
- A flood defence consent – if the proposed site is near a main river or a flood defence.

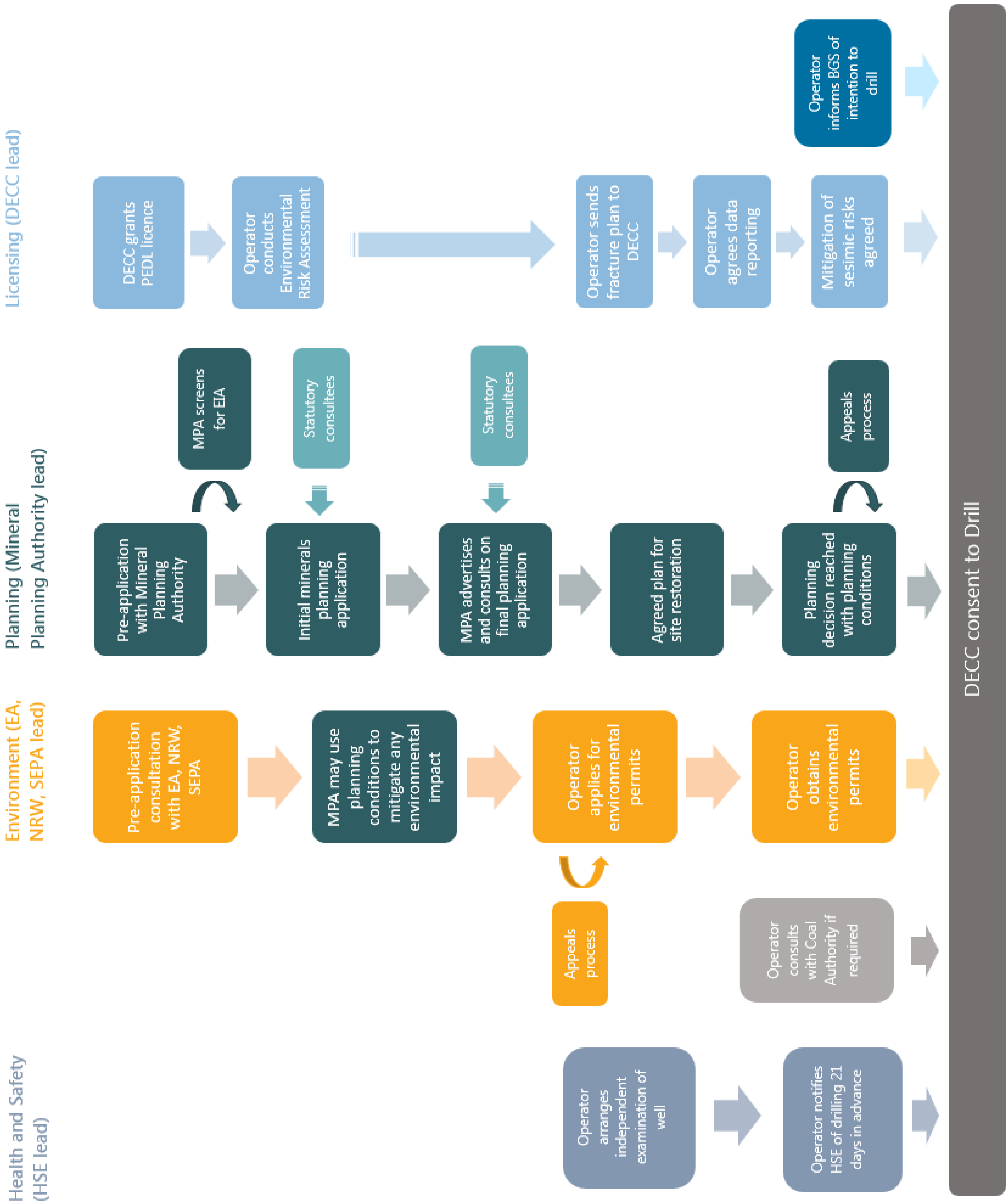


Figure 2.6 Regulatory Roadmap

In applying for a permit, an operator will be required to provide information including a geological assessment, casing design detail and hydraulic fracturing fluid composition. The Environment Agency has developed some standard rules permits for the management of waste generated from onshore oil and gas to reduce the need for bespoke permits and speed up the process[xxxi]. Permit applications will aim to be determined within 13 weeks. However where there may be a 'site of high public interest' the consultation period will be extended and may take between four and six months to determine. The EA is also a statutory consultee for planning applications and EIAs associated with unconventional oil and gas.

Following planning consent and environment permitting the operator will need to notify the HSE. The HSE monitors shale gas operations from a well integrity and site safety perspective, under the *Borehole Site and Operations Regulations 1995* and the *Offshore Installations and Wells (Design and Construction, etc) Regulations 1996* which despite its name also applies onshore[xxxii]. At least 21 days before drilling is planned, the HSE must be notified of the well design and operation plans to ensure that major accident hazard risks to people from well and well related activities are properly controlled. Together the EA and the HSE must be satisfied that wells are designed, constructed and operated to standards that protect people and the environment.

The operator must also notify the BGS with details of the drilling and permission must also be obtained from the Coal Authority if the well encroaches on any coal seams. Finally DECC will provide consent to drill after scrutinising fracture plans and once any controls to mitigate seismic risks are put in place alongside any arrangements for venting or flaring. The landowner is also able to impose conditions. The Secretary of State must also give Fracturing Consent.

Should adequate reserves be found and it is viable to exploit them, a separate planning permission would be required to extract the oil or gas. It remains to be seen what the regulatory process will involve for production. CIWEM considers improved environmental protections such as 'green completion' technologies should be added as best practice. Green completion technologies are used in the US and separate out gas, water and sand in the flowback fluid before directing the recovered gas into pipelines. This means that methane and carbon dioxide emissions are reduced compared to venting and flaring methane, provided the gas is sold or otherwise used[xxxiii]. A BAT document on reduced emissions completions is due to be published in 2016.

Industry code of practice

In addition to the regulatory framework, an industry code of practice has been developed by UKOOG (UK Onshore Oil and Gas) with the input of DECC, EA, SEPA, HSE. The Onshore Shale Gas Well Guidelines[xxxiv] were first published in February 2013 and the third edition was published in March 2015. These guidelines cover best practice for shale well operations in the UK and detail the Hydraulic Fracturing Programme (HFP) which is required as part of DECC consent and covers groundwater isolation, fracturing containment and induced seismicity. They also emphasise good data, measurement and transparency as vital to secure public confidence.

UKOOG has also produced guidelines for establishing environmental baselines for soil, air and water[xxxv] and guidelines for addressing public health in EIAs[xxxvi]. These guidelines are not mandatory but failure to comply with them may lose the operator membership of the trade body.

Public acceptance

The potential for local opposition to planning applications is likely to be significant. A large number of 'anti-fracking' groups have already appeared across the country and have been vocal (and physical) in their protest to the visual and physical disruption associated with the industry alongside its risks to the environment and health.

Councillors have been under pressure from their constituents to block planning applications. This has been the case in Lancashire where large numbers of responses have been submitted to their planning consultations. Lancashire County Council refused planning applications from Cuadrilla for drilling, fracking and flow testing and also the associated monitoring arrays for two sites. The Roseacre Wood site was refused for an "*unacceptable and potentially severe impact on the road network, both in terms of traffic and the increased danger to other road users*" and Preston New Road was refused on "*grounds of noise and visual impact*"[xxxvii].

The Government has introduced new measures to speed up the planning process. Any councils that repeatedly fail to determine oil and gas applications within the 16 week statutory timeframe will be identified with subsequent applications potentially decided by the DCLG Secretary of State[xxxviii]. Shale gas extraction may also in future fall under the Planning Act regime with the DECC Secretary of State able to determine applications as Nationally Significant Infrastructure. Whilst both these moves could make the planning process easier, it is likely to inflame the situation with local communities and pressure groups who consider that their rights are being affected. Cuadrilla's planning appeals have now been referred to the Planning Inspectorate and DCLG Secretary of State with locals fearing their voices will not be heard.

It is positive for the industry that the planning officers were satisfied with Cuadrilla's plans for drilling and fracking and also with measures relating to air quality, greenhouse gas emissions and water use aspects. However a key concern relates to disruption from vehicle movements. During the construction, exploration and early production phases the work is intensive and for 24 hours a day. Once constructed, pads, according to industry advice, may be approximately the size of a football pitch, with the well projecting only a few metres in height with minimal visual disruption.

The Environmental Statement for the Roseacre Wood site states that on average during the two month construction period there will be 22 two way HGV movements per day, during five months of drilling 14 two way HGV movements a day and for one to two months of fracturing 10 two way HGV movements a day[xxxix]. At the site, the water for hydraulic fracturing was due to be sourced from the mains supply and flowback fluid reused on site, reducing the requirement for high number of HGV movements to transport water. It is a concern for the industry that the Council believed the disruption from traffic to be too high when it could be far greater at other potential shale gas sites.

The Government has taken steps to reduce the burden on the industry as far as land use planning is concerned. It has removed any requirement for shale gas operators to serve notice to landowners or tenants of the land beneath which gas may be extracted[xl]. This is because the exact routes of lateral drilling will not be known at the application stage since this will depend on the geology, which can only be accurately known once drilling has commenced. The rationale for not serving notice is that the area is widely drawn and it would be unreasonable and impractical to reach the significant number of landowners.

In the context of planning objections by local communities, it is worth noting that the UK's onshore oil and gas industry already has 120 sites, the public awareness of which is apparently low, despite the fact that hydraulic fracturing has taken place at several of these sites for 30 years[xli]. This shows that the industry can be co-located with other stakeholders and operate effectively and safely. Shale gas operators will need to continue to earn public trust through careful planning, engagement and adherence to best practice to ensure the same footing as the conventional oil and gas industry.

Community engagement charter

UKOOG has established a binding Shale Community Engagement Charter[xlii] for its members that covers how operators will communicate and engage with local communities and also makes specific commitments with respect to logistics, health and safety, environmental compliance and local needs. It is important that as the industry develops these are adhered to.

Financial incentives

The Government has backed a pledge made by UKOOG to introduce an incentive package for local communities, comprising £100,000 for communities sited in the vicinity of exploratory wells and one per cent of revenues from production. With mineral rights in the UK being vested by the Crown Estate and licensed by DECC the incentive package has to come from the industry. This is a far cry from the situation which prevails in the US, where in some states property owners have mineral rights and up to 20 per cent of production revenues may be paid to individual land owners[xliii].

Councils will also be allowed to keep a hundred per cent of the business rates they collect from shale gas sites, which is double the usual 50 per cent figure[xliv] (although by the end of this Parliament this will be extended to all industries[xlv]).

In November 2015 the Government set out proposals on the design of a new sovereign wealth fund for communities hosting shale gas developments. The Government will commit up to ten per cent of shale gas tax revenues to a Shale Wealth Fund, which could deliver up to £1 billion of investment in local communities hosting shale gas developments, in the north of England and other shale-producing regions. The point to note is that the figure is 'up to' ten per cent so it remains to be seen how much will feature in practice.

Economics, market access and political limitations

The geopolitical factors associated with the supply of gas to the UK are of major interest. With the decline of North Sea oil and gas supplies, the UK is increasingly reliant on gas supplies from locations of potential political instability such as Russia and Qatar. The attractiveness of a potential new indigenous supply of hydrocarbons is thus understandable geopolitically speaking and given the country's continued reliance on gas. Yet a key question mark hangs over the costs associated with extracting domestic shale gas and the political rhetoric surrounding lower consumer bills has been widely questioned by economists[xlvi].

The shale gas boom in the US resulted in no small part from a number of crucial factors which made it highly economically attractive. That landowners often own the rights to minerals beneath their own land provided an enormous economic incentive for them to allow exploitation of any gas reserves present (and has made many people wealthy as a result). Secondly, the existence of a substantial onshore oil and gas service industry which was able to develop solutions to unconventional hydrocarbons quickly, combined with highly favourable geology, resulted in low production costs (as low as $3 (£1.8)/British Thermal Unit (MBtu)[xlvii]).

Additionally, environmental regulation of the industry varies significantly between states and has been taken advantage of where it is relatively relaxed compared to the regime in the UK and wider Europe. For example in many regions wastewater is allowed to be injected underground for disposal making the process much more economically viable rather than having to undertake expensive treatment technologies. Under current plans this will not be allowed in the UK and reinjection will only be allowed for future well stimulation in certain circumstances.

The Institute of Directors has suggested UK shale gas production could peak at £3.7 billion a year, supporting 74,000 jobs[xlviii]. Similar conclusions were drawn by EY[xlix], which focused on the viability and benefits of developing a UK supply chain and skills requirements for the shale gas industry, estimating around 65,000 jobs could be created. However, these estimates depend critically on the cost of extraction.

Production costs are likely to be higher in the UK, a reflection of the more challenging geology, greater regulatory burden and other social pressures requiring mitigation measures to reduce the physical impact of the shale gas industry. They are estimated to be within the range of $8-12 (£5-7))/MBtu[l].

The Government has recognised the high upfront costs associated with shale gas projects and put in place a taxation arrangements to assist the development of the industry such as the increased business rate and the *Finance Act 2014* provides a 'pad allowance'. This cuts the tax on a portion of production income from 62 per cent to 30 per cent at current rates[li]. The industry is still young and advances are occurring at a good pace elsewhere, meaning that exploitation costs are quite likely to fall over coming years and decades. Innovation in technologies for wastewater treatment is likely to be necessary to make shale gas economically attractive in the UK.

In the US, the gas market is largely domestic, due to strong levels of domestic demand and an undeveloped export industry (although this is now being expanded in response to strong supply). This allowed the sudden influx of cheap shale gas to reduce the wholesale price dramatically. Gas prices in the UK are less liquid than those in the US, with the UK having closer ties to the European and Asian supply markets which are traded on a longer term basis, so a reduction in price and any associated stimulus to the economy is likely to be significantly less marked. Oil and gas prices have fallen in the UK over the last 18 months (partly due to lower than anticipated world demand, but also partly due to higher supply, including from US shale gas) so the higher production costs may not be offset by achieving a higher wholesale price.

Greenhouse gas emissions

The UK has a legally binding *Climate Change Act*[lii] which established a framework to develop an economically credible emissions reduction path and a target of reducing greenhouse gas emissions by at least 80 per cent by 2050 (compared to 1990 levels). This means that significant changes will be required in the short and medium term to the UK's energy generation and consumption.

The effect of cheap natural gas from shale in the US has had a positive impact on domestic greenhouse gas emissions as it has reduced coal consumption (although this has been displaced by an increased use of coal in Europe). Yet shale gas is still a fossil fuel and its extraction can also release fugitive emissions, so its role in the energy mix has to be questioned.

Due to conflicting reports on the potential quantities of fugitive emissions, the UK Government commissioned a study[liii] to review all the available evidence. This found that if adequately regulated, local greenhouse gas emissions from shale gas operations should represent only a small proportion of the total carbon footprint of shale gas. However this is subject to the caveats that shale gas will replace current LNG use and the increase in cumulative emissions (as it is a fossil fuel) will have to be counteracted in other areas.

There is a risk that the development of a shale gas industry could worsen the situation for the UK to develop renewable energy sources. The Task Force on Shale Gas notes that for shale gas to serve appropriately as a transitional fuel it must be clearly demonstrated that this will not prohibit or slow the development of renewables and low carbon energy[liv]. It recommends investment in innovation in Carbon Capture and Storage (CCS) and low carbon energy generation, storage and distribution. In the longer term any fossil fuel electricity generation infrastructure will have to have CCS technology if it is to provide significant amounts of generation as part of a low-carbon energy mix. This is still a long way from commercial reality, with the Government cancelling its latest investment plans.

The independent Committee on Climate Change's view is that a well-regulated shale gas industry could have economic benefits to the UK and reduce dependence on imported gas[lv]. However it states that to meet the fourth carbon budget to 2027 under the *Climate Change Act*, it must be regulated sufficiently to ensure that fugitive methane emissions are low and it must be accompanied by a strong commitment to reduce all greenhouse gas emissions. Its fifth carbon budget (covering the period 2028-2032) report does not explicitly consider shale and it will instead publish a report in early 2016 assessing the compatibility of shale gas extraction in the UK on carbon budgets to 2050. CIWEM considers the strategic lead role for gas must be set within clear decarbonisation targets and alongside renewable energy and energy efficiency policies.

3. Risks to the water environment and how they can be managed

Water has become a major focus of public concern in the development of a shale gas industry. Any impacts on water are likely to be local in extent and dependent on whether the geographical location of any productive areas of geology coincide with areas of particular water resource pressure, or are near to important groundwater resources or sensitive aquatic environments.

This chapter investigates:

- How much water will be needed for the processes of drilling and fracturing a shale gas well
- Where the water will be sourced and how it will be transported to the site
- Whether there will be enough water available in the future as an industry develops
- What chemical additives the fracture fluids will contain
- The potential for contamination of groundwater or the local environment from poor well design or well failure or from the mobilisation of solutes or methane
- How to prevent contamination from surface water flooding and run off
- The risks from the storage and transportation of the returned fluids
- The potential for reuse of wastewater in the hydraulic fracturing process
- Whether there is the treatment capacity to appropriately treat the flowback and produced water
- How to protect groundwater during and after the decommissioning of a well

Water resources

Water is a renewable but finite resource. It has an economic value in all its competing uses, except crucially that for the environment. The failure to value water for environmental needs has been the root cause behind a large number of examples of environmental degradation.

Water abstraction is the process of removing water from natural sources such as rivers, lakes and aquifers and is regulated through a system of licences. Over-abstraction can result in a decrease in the availability of public water supply, adverse effects on aquatic habitats and ecosystems from water quality degradation, changes to water temperature and erosion. There is also the potential for the underlying geology to become destabilised due to upwelling of lower quality water or other substances and as a result of a reduction in pore water pressure.

Demands on water vary across the UK and the amount of water available for use also varies geographically and temporally. The environmental regulator is responsible for deciding the maximum amount of water that may be taken from the environment for domestic and business use, without compromising environmental needs.

How much water is needed?

There are various processes involved in extracting shale gas and these involve differing amounts of water: drilling, hydraulic fracturing and production (if there is re-injection). The amount of water required for a given process will also vary from location to location.

The process of hydraulic fracturing, as shown in figure 2.4, is typically carried out in stages to fracture the shale progressively along the horizontal wellbore (lateral). This may take a few weeks with the hydraulic fracturing of each stage taking around a day. Sites tend to alternate the operation between perforating a length of casing and then fracturing the rock, with each element taking around 24 hours in a non-stop rotating operation. Once the well has been drilled and hydraulically fractured, a significant amount of fracturing fluid (up to 80 per cent) returns to the surface as flowback fluid.

Overall, when compared to the life time of a shale gas well the period for water demand is quite short and focussed at the early stages of the well's development. Figure 3.1 shows the range of volumes for each stage and a comparison with regional and national water demand/abstraction. The variation in estimates of water use reflects the complexity of drilling, geological conditions, borehole depth, pressure, thickness of the gas reservoir and other factors. These scenarios are for a well (i.e. one lateral well). As suggested earlier, the geology of the UK may provide more opportunity to drill a number of horizontal wells from the same vertical well.

Process	**Water use per well (one lateral)**			**Duration**
	BGS figures[lvi]	UKWIR figures[lvii]	USEPA figures[lviii]	
Drilling	0.25 – 4Ml	1-2 Ml		2 – 8 weeks
Hydraulic fracturing	7 – 23 Ml	10 – 20 Ml	5.7Ml (median)	5 – 7 weeks
Production	0 Ml (potential for reuse of returned water)			5 – 20 years
Comparison				
United Utilities water demand (Regional)			12,180 Ml	1 week
United Utilities water lost through leakage (2013/14)[lix]			452 Ml	1 day
National groundwater abstraction			42,000 Ml	1 week
National surface water abstraction			119,000 Ml	1 week

Figure 3.1 Comparison of water use and duration for stages of the hydraulic fracturing process. There is also water use associated with the processing of proppant. Figures for comparison from AMEC[lx].

NOTE: 1Ml = 1000000 litres | = 1000m³ | = 219969 gallons | = 35314.7 cubic feet

To put this into perspective, to meet ten per cent of the UK gas demand from shale gas over 20 years (9bn m^3 gas) would require 25 – 33 million m^3 of water, or 1.2-1.6 million m^3 per year[lxi]. Although this may sound a large amount, when compared to licensed water abstraction per year in England and Wales (12.6 x 10^3 million m^3) it equates to less than 1/10th of one per cent of total abstraction[lxii].

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. The key question will be how many wells there will be in a given area and over what timeframe they will be hydraulically fractured? The likely production scenario will see multiple wells stimulated across a field development, with many wells in production at the same time, depending on the number of operating sites. Modelling by UKWIR[lxiii] has shown that for a regional scenario of 1000 wells, the estimated peak demand is 2.2 Ml/d. As figure 3.1 shows the amount of water a single water company might be asked for is small in comparison to other demands and is a fraction of what may be lost in leakage. This is just one scenario and many others are possible, for instance with more recycling of water the demand would be less, but it is indicative of the likely scale of water use.

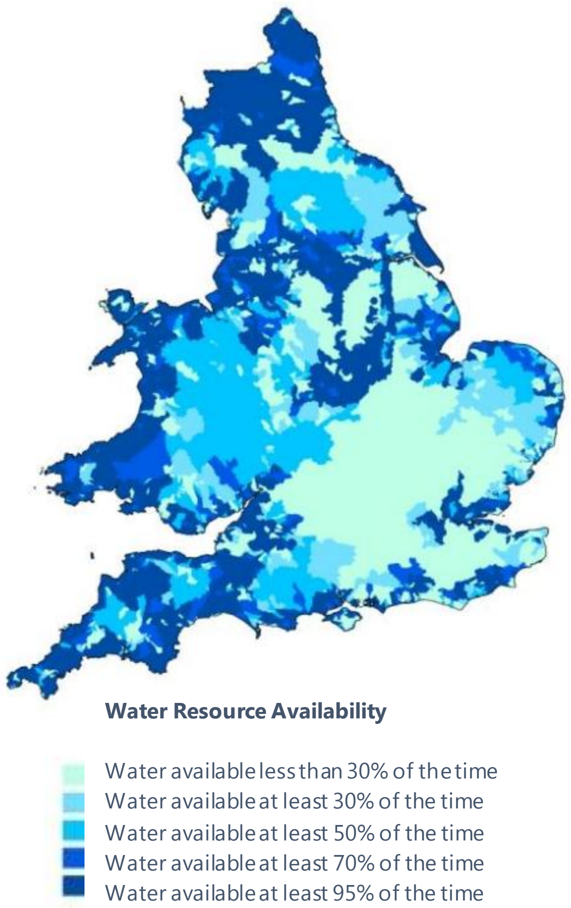
Compared to other fossil fuels, experience from the US has shown that the water intensity of shale gas production is relatively low: (0.6 – 1.8 gal/MMBtu (million British Thermal Units) for shale gas, 1 to 8 gal/MMBtu for coal mining and washing, and 1 to 62 gal/MMBtu for onshore oil production[lxiv]). The difference being with shale gas is that the water consumption is front loaded, used in the drilling and fracturing stage, so there is a large upfront water usage over a few days or weeks, after which the natural gas is produced over many months or years. As the hydraulic fracturing process itself is short, operators may be able to choose the optimal time to fracture to avoid coinciding with times of water stress and drought.

However this analysis does not include the full lifecycle of water use, should the gas be used for electricity generation. If this is the case then it has been reported that for the Marcellus shale in the US, only 6.7 per cent of water consumption occurred upstream in the fracturing process (56.8 L/MWh), while 93.3 per cent of fresh water consumption occurred downstream for power plant cooling via evaporation (791.2 L/MWh)[lxv].

Where will the water come from?

Water sourcing is largely a local issue as by its nature water can be energy intensive to transport. Water interconnectivity is fairly limited in the UK although more water transfers and trades are beginning to take place. Shale gas operators have the option to source water directly from the environment via abstraction, purchase it from a water company and receive it via the mains or from tankers, or they may recycle a proportion of their own water.

If they source water from the local area by abstracting it directly from a river or groundwater source they will need a licence from the relevant environmental regulator. A licence would only be granted where there is a sustainable source of water as assessed by the Environment Agency's Catchment Abstraction Management Strategy (CAMS) (see figure 3.2). Potential abstractors also need to demonstrate to the EA that their operations will not damage European Habitats and Birds Directives sites before an abstraction licence will be granted.



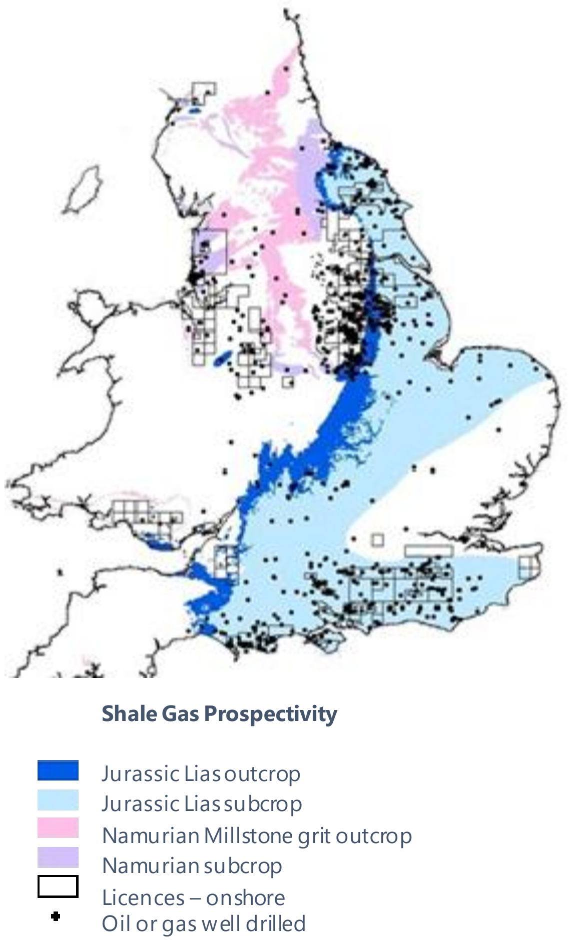


Figure 3.2 Water resource reliability: percentage of time water would be available for abstraction for new licences. EA and CEH, 2012[lxvi].

Figure 3.3 Shale gas prospectivity, 2013, DECC[lxvii].
NOTE: Licences do not distinguish between shale gas and other forms of hydrocarbons.

The CAMS process provides information on how much water is available for future abstraction licensing (new water resources) on a catchment by catchment basis[lxviii]. The 2012 analysis shows that twenty five per cent of water bodies in England and seven per cent of water bodies in Wales will provide a reliable source of water for abstraction for less than 30 per cent of the time (pale blue in figure 3.2)[lxix]. This means that there are unlikely to be many new abstraction licences issued in these areas or the current ones may be redistributed under abstraction reform.

Where water stressed catchments coincide with shale gas licence areas, operators will need to be aware of the risk that water may not be available in the future. The north west is generally much less water stressed than the south east (in terms of the overall supply-demand balance, except for a few zones such as Cumbria). Early engagement with the EA or local water company, depending on where the water is sourced, will be important to ascertain available volumes. CIWEM considers companies should continue to work to improve the accuracy of their water consumption and production estimates to help establish any pinchpoints in supply and treatment. This point is returned to in *future water resource availability*.

Operators may source water directly from the public water supply. The exploration that has begun to taken place in the UK such as Cuadrilla's in the north west utilised water from the mains supplied by United Utilities. Under the *Water Industries Act 1991*[lxx] a water company has a duty to provide water for non-domestic purposes but this is subject to certain exceptions. Usage of mains supply requires the agreement of the water company, and that such supplies are available. If a public water supply is used then any additional infrastructure that will have to be put in place to transport the water will be at the expense of the shale gas operator.

If there is no network nearby, a shale gas operator can purchase the water from a water company and have it transported by tanker. Although tankering can solve problems with local water stress and the need for water infrastructure, there are the additional impacts from intense truck movements which have been a major cause for concern in the US and have the potential to cause a problem in achieving planning permission. The road network may also need to be reinforced in some of the prospective areas of shale gas to support the increased number of vehicle movements, and there is an additional health and safety risks from accidents or spills.

There may be scope for larger companies to recycle their produced water to stimulate future fractures (see page 48 for further on this). Some have also suggested the use of seawater to avoid the water stress issue. However the water used does have to be of a certain input quality; treated water is more appropriate as it is already clean and has a built in biocide from the chlorine that is routinely added to supply. At present it is cheaper to use pre-treated mains water than to treat seawater so it is likely that this practice will continue. Research is also underway to look into hydraulic fracturing with lower quality waters and also waterless techniques.

The industry body Water UK claim that in reality, water sourcing is likely to vary from site to site. It foresees a number of approaches, with a connection to the mains augmented with recycled water, on site storage and tankers to meet the peak demands[lxxi]. The configuration may vary locally and perhaps even seasonally.

Future water resource availability

With production not expected until further into the 2020s[lxxii] it is worth looking at future water resource availability. Water availability is due to decline in the future due to the increasing demand of a growing population and the reduced quantity that will be permitted to be taken from the environment as a result of the impacts of climate change, sustainability reductions required under the Water Framework Directive and the Government's intention to reform the abstraction regime to correct historical over-abstraction.

The European Water Framework Directive (WFD)[lxxiii] came into force in 2000 and was transposed into UK law in 2003. Its purpose is to enhance the status, and prevent further deterioration, of the ecology of aquatic ecosystems and their associated wetlands and groundwater. Around 13 per cent of river water bodies in England and four per cent in Wales are failing to support Good Ecological Status due to over abstraction[lxxiv]. As a result the WFD requires water companies to take less water out of natural resources in the form of 'sustainability reductions'. This could be up to eight per cent per AMP (the water industry's five year asset planning cycle).

One of the biggest pressures on water resources is projected population growth. By the 2030s, the population of England is expected to grow by an extra 9.2 million people and 0.4 million people in Wales[lxxv]. This is not evenly distributed with London, the east and the East Midlands regions all projected to grow at a faster rate than the rest of the country[lxxvi]. Combined with other trends, such as the increasing number of smaller households which can lead to rises in personal consumption, overall demand for water is likely to grow, with some scenarios suggesting growth of around five per cent by 2020 and as much as 35 per cent by 2050[lxxvii].

Climate change is likely to alter the water cycle significantly in the future. The amount and distribution of rainfall will vary[lxxviii], a reduction of 40 per cent in summer rainfall by the end of the century may occur in the south of England[lxxix] and there are likely to be changes to the frequency of drought conditions[lxxx].

The geology, soils and vegetation of the UK are varied, and these lead to different hydrological responses to rainfall. In the north and west of England the surface geology is relatively impermeable so rainfall tends to run quickly into streams and rivers and water sourced from surface water dominates. In the south and east, chalk rock and the overlying superficial deposits are more permeable leading to water sourced from groundwater. Surface water responds more quickly to rainfall events than groundwater.

Our current understanding of the impact of climate change on water resources in England and Wales is based on the Future Flows[lxxxi] project by Defra, BGS, CEH and partners. This work used the UKCP09 scenarios and ran them through river flow and groundwater models to produce river flow maps of changes for the 2050s. There are large uncertainties around the extent of the changes. Most scenarios indicate decreases in flows, especially in the south and east (up to -80 per cent) whilst in the west and north changes can be small:

- *For surface water in winter there is a mixed picture with between a +40 per cent or -20 per cent change in water availability. In summer scenarios predominantly show decreases in runoff, ranging from +20 per cent to -80 per cent.*

- *The picture for groundwater is still unclear. Early results suggest that in some climate scenarios increased winter rainfall leads to increased recharge and higher groundwater levels that persist into the summer, but in others recharge reduces, leading to lower groundwater levels and reduced availability of groundwater for abstraction.*

The Environment Agency's report on current and future water availability[lxxxii] uses scenarios to combine the impacts from the pressures on water resources in the future and predicts an overall decrease in the amount of water available. It is for Water Companies to plan for how they will meet these challenges. Water Resource Management Plans (WRMPs) are produced every five years by water companies to assess how much water will be needed for the next 25 years.

Although current abstraction licences issued take into account population growth and climate change to protect the environment, existing licences that may have been granted decades ago may not provide the level of protection that is required today. As a result Defra and the Environment Agency are currently looking at reforming the abstraction system to consider alternative options for water allocation and charging while protecting environmental flows in the future. This means there may be fewer licences or volumes per licence available from 2020 which could affect shale gas operators.

Water resources in the north west can be prone to drought as it is typically surface water fed and is predicted to have the largest percentage decrease in rainfall from climate change. Many of the locations of onshore licences on the Weald in the south east coincide with areas that are already over-abstracted and where fewer resources will be available in the future (figures 2.2 and 2.3). Recent estimates based on Environmental Flow Indicators for each water company in the south east suggested that the total target of sustainability reductions could be as much as 50 per cent higher than original estimates from the Environment Agency[lxxxiii]. This is a considerable challenge to the companies who must also deal with increased demand and the pressures of climate change.

However the south east does have scope to share extra headroom. Currently Southern Water can receive 15 million litres water a day from Portsmouth and supply 31 million to South East Water, 1.3 million to Affinity and 0.3 million to Wessex Water. Water Transfers are likely to become more common locally as a result of the *Water Act 2014*.

Following the determination of the 14th round of licences United Utilities, Southern Water, Yorkshire Water and also now Anglian may have an interest in the development of a shale gas industry. United Utilities, which has been engaged with the industry for the last few years, state in its Water Resource Management Plan: "*We do not consider provision of such services for shale gas companies would impact on our resources. The strong regulatory framework to grant the licence for shale gas exploration to proceed will take into account environmental concerns and risks to water supplies*[lxxxiv]".

The retail market for non-domestic water users will open in 2017 allowing businesses to choose where to source their water. This will be helpful to the larger operators who have sites in different water company boundaries as they will be able to make efficiency savings. It is worth noting that the water itself will be the same (i.e. composition) and responsibility will remain with the wholesaler.

A Memorandum of Understanding (MoU) has been signed by the industry bodies UKOOG and Water UK specifying that the shale gas industry should produce "*onshore oil and gas company development plans, including scenarios for expansion of exploration and development within a local area and what this means for short and long-term demand for water at specific locations*"[lxxxv]. This is welcome but may need to be updated to include any new water retailers.

CIWEM previously called for water companies to become statutory consultees in the planning process of shale gas operations to ensure that they are engaged with from the outset to plan for future water demand and any associated water treatment. It is welcome that this has now been implemented as a result of the *Infrastructure Act 2015* in the *Town and Country Planning (Development Management Procedure (England) Order 2015*.

Potential for contamination of groundwater and the local environment

A frequently expressed concern associated with shale gas operations is that contamination of groundwater could occur. This may result from a catastrophic failure or loss of integrity of the wellbore, or if methane or contaminants can travel from the target fracture through subsurface pathways[lxxxvi]. There is also the potential for pollution of the local land and water environment if the returned water from the hydraulic fracturing process is not appropriately contained, managed, and treated prior to eventual disposal. Any material spilt on or applied to the ground has the potential to reach the water table.

Hydraulic fracturing fluid composition

Hydraulic fracturing fluid is generally made up of water, sand and chemical additives (figure 3.4). Approximately 90 per cent is water. A proppant is added to keep the induced fractures open in the rock; this is a granular material, usually sand. Other commonly used proppants include resin-coated sand, intermediate strength proppant ceramics, and high strength proppants such as sintered bauxite and zirconium oxide. After water and sand, chemical additives make up 0.05 – 2 per cent of the hydraulic fracturing fluid. These may be added to act as biocides, acids, friction reducers, corrosion inhibitors, gelling agents, scale inhibitors, pH adjusting agents etc.

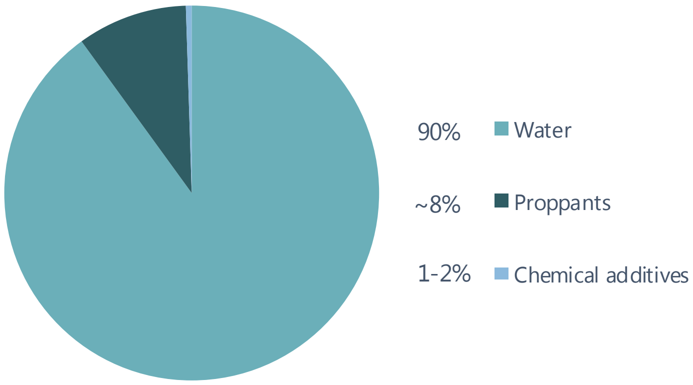


Figure 3.4 Typical constituents of fracture fluid[lxxxvii]

In the US the typical constituents include hydrochloric acid, polyacrylamide, isopropanol, potassium chloride, ethylene glycol, sodium carbonate and citric acid[lxxxviii]. There has been much controversy in the past over the disclosure of chemical additives within hydraulic fracturing fluids in the US; when a Congressional Committee launched an investigation into products used between 2005 and 2009, it found the use of toxic and carcinogenic substances, such as benzene and lead[lxxxix].

The UK is keen to avoid such controversy. Using information from the shale gas operator the EA will assess whether an additive is hazardous or a non-hazardous pollutant using a methodology that follows the requirements of the Groundwater Daughter Directive and under the EA technical guidance WM2[xc]. The Directive requires that no hazardous substances are allowed to enter groundwater and that non-hazardous pollutants do not cause pollution. The EA expects shale gas operators to propose only non-hazardous substances. Cuadrilla has disclosed that it has only used polyacrylamide in fracturing activities to date.

Shale gas operators will need to keep EA informed of the nature and quantities of the chemicals they propose to use in the hydraulic fracturing process, including carrier fluids, at the pre-application and planning application stages. They will also need to confirm their proposals at the permitting stage. This ensures that the proposed borehole construction, casing and completion can be assessed as adequate. Approval for the use of chemicals in shale gas operations will be considered on a case by case basis as part of the environmental permitting process. Allowing the use of a chemical at one site may not mean it will be automatically allowed elsewhere as the site conditions and environmental risks may vary.

There is however a concern that as the production phase is reached, to achieve greater drilling efficiencies, companies may push for the use of more chemicals or more hazardous chemicals to be used. In the UK under European REACH regulations if more than one tonne per year of a chemical is to be used, the chemical has to be registered and assessed for the specific use. Each EU member country is responsible for appointing a regulatory agency (the EA) who is responsible for ensuring that REACH regulations are abided by. Under UKOOG guidelines all operators will be expected to disclose all chemicals by name, volume and concentration on their website and also on UKOOG's website.

On-site spills or leaks could potentially occur during the transportation of chemicals to the site and in the mixing and preparation of hydraulic fracturing fluids (see more on storage and transportation below). The baseline monitoring of aquifers and surface water prior to any activity as well as continuing monitoring during and after production will help detect any leaks or spills. Any monitoring programme should focus on the detection of the chemicals used in the fracturing fluid[xci].

Groundwater protection

Groundwater supplies about one third of mains drinking water in England and up to 10 per cent in Wales. It also supports numerous private supplies. Groundwater is water stored below the water table in rocks or other geological strata called aquifers. Depending on the overlying geology, groundwater may be protected from contamination from the overlying soil and rock. Where there is little or no natural protection, protecting groundwater is essential as once it becomes polluted it is difficult to clean up[xcii]. Groundwater is protected by the environmental regulators and under existing regulations shale gas companies can be prosecuted if they cause pollution.

Drinking water

Under the European Water Framework Directive, water bodies that are used for the abstraction of drinking water have to be delineated and designated drinking water protected areas (DrWPAs). All groundwater bodies in England and Wales are classified as DrWPAs due to the low abstraction thresholds set in the Water Framework Directive. Article 7.3 requires the protection of these water bodies "*with the aim of avoiding deterioration in their quality in order to reduce the level of purification treatment required in the production of drinking water*".

The potential for shale gas extraction and related activities to impact on public *drinking* water supplies is considered minimal as the *Water Supply (Water Quality) regulations* provide for the protection of the public from any substance or organism likely to cause a threat to public health. The regulations require Water Companies to assess risks to their supply systems, identify any potential hazards and have appropriate mitigation measures in place. Local authorities will also need to consider the implications for their risk assessments of private water supplies.

Aquifers and source protection zones

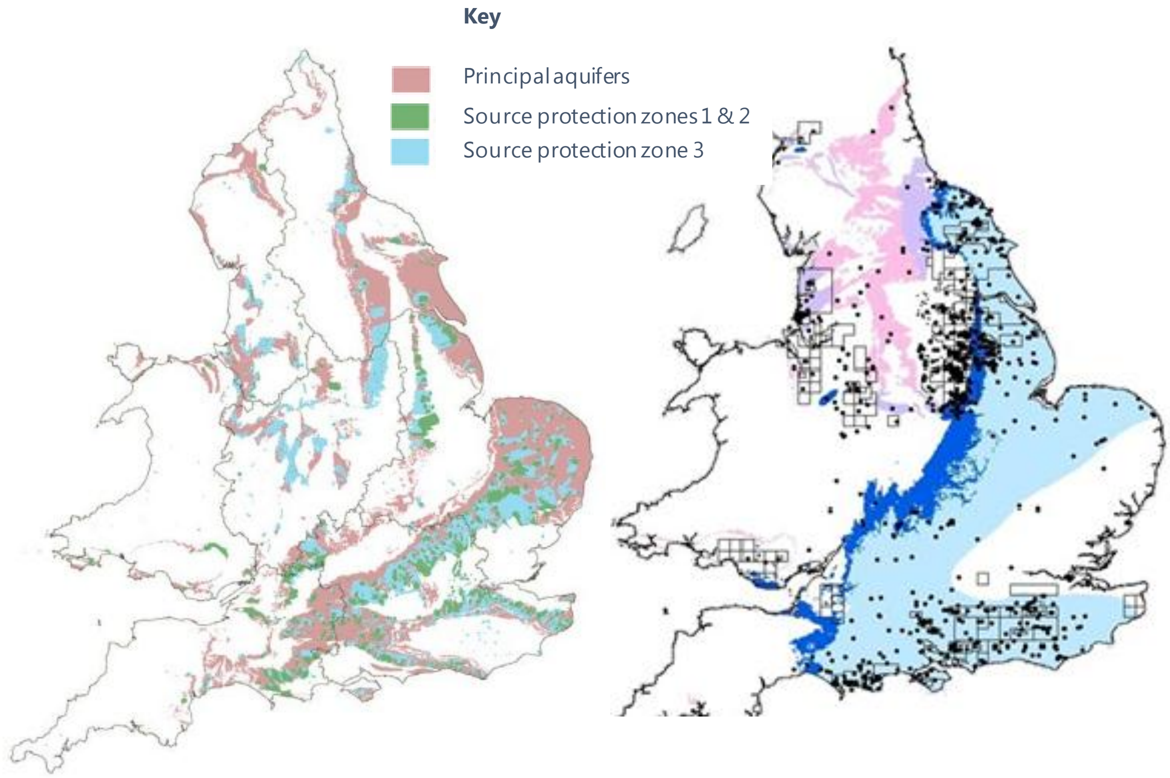


Figure 3.5 Principal aquifers and source protection zones in England and Wales, 2013, EA[xciii]

Figure 3.6 Shale gas prospectivity, 2013, DECC[xciv]

Figure 3.5 shows the locations of principal aquifers (that provide most of groundwater for public water supply) and source protection zones in the UK. There is an overlap in the north west, north east and south east with hydrocarbon licence areas (figure 3.6), although these maps do not illustrate the underlying geology or depths of aquifers. The UK has a complex geological sequence that needs to be understood to assess the risks. The BGS and EA have produced a set of national scale maps showing the spatial relationships between Principal Aquifers and major shale units in England and Wales[xcv]. In addition, a series of separation maps[xcvi] show the vertical separation between pairs of shales or clays and overlying aquifers. The BGS and the Environment Agency are currently extending this work to include Secondary Aquifers which is due in 2017. These provide less water for public supply but are important for private drinking water supplies.

The *Infrastructure Act 2015* placed additional safeguards in England and Wales which prohibits hydraulic fracturing onshore at a depth of less than 1000 metres and within protected groundwater source areas[xcvii]. These provisions are enacted in the *Onshore Hydraulic Fracturing (Protected Areas) Regulations 2015*[xcviii] which further restrict hydraulic fracturing to below 1200 metres in SPZ1 and in National Parks, the Broads, Areas of Outstanding Natural Beauty or a World Heritage site. Rules on what activity can take on the surface of protected areas will be delivered through Petroleum Exploration and Development Licences (PEDLs) for onshore activities. Current proposals for this also rule out Sites of Special Scientific Interest, Ramsar and Natura 2000 sites.

As a statutory consultee in the shale gas planning process the Environment Agency can object to shale gas extraction infrastructure or activity through planning or permitting controls[xcix]. It has stated it will object where the activity would have an unacceptable effect on groundwater, or if it is close to sensitive receptors it will adopt the precautionary principle.

The Environment Agency also expects operators to demonstrate best available techniques to protect groundwater (for example through the use of onsite storage, appropriate bunding and linings and the use of water based drilling muds). The monitoring regimes will also be set out within permit applications. Operators will be required to produce a hydrogeological assessment conducted by a specialist at the planning and permitting stages and when submitting an intention to drill a borehole. This should evaluate any risks to groundwater from substance used or released from drilling and well stimulation activities[c] and assure that fractures cannot leave the target formation.

Contamination of groundwater from poor well design or failure

Wells can provide the pathway for pollutants, particularly if a casing or cement are inadequately designed or constructed or fail. The design and number of casings of the well are determined by its depth and the zones of separation.

During drilling the operator must case off the aquifer and pressure test each casing before changing to a non-freshwater mud or on encountering hydrocarbons. Cementing is a critical part of well construction and is a fully designed and engineered process. The cement must be properly set or the gas has an easy access route up to the aquifer along the annulus outside of the pipe. Best practice is to cement casings all the way back to the surface, depending on local geology and hydrogeology conditions[ci]. Operators should use best available techniques[cii] and industry standards for cement to ensure risks are minimised. Cement evaluation tools often known collectively as cement bond logs can be used to support other evidence to determine if the casing has been successful or not.

On completion of drilling, the process of hydraulic fracturing and any induced seismicity could itself damage the well casing and affect well integrity. The OGA requires operators to delineate faults in the area of the proposed well to identify the risk of activating any fault by hydraulic fracturing. Seismic monitoring must take place to assess induced seismicity and thus potential impact on well integrity using a traffic light monitoring system. If a seismic event is determined to be large enough by the monitoring system then operations will cease. The well can then be repaired.

The Environment Agency expects that where a shale gas development does proceed, there will be established good practice in groundwater protection applied where any associated drilling or operation of the boreholes or shafts passes through a groundwater resource. Groundwater including any local aquifers should be carefully delineated by the operator as part of the well design and fracturing risk assessment process. If any aquifer is in contact with the well then it must have at least three layers of casings (figure 3.7).

The *Offshore Installations and Wells (Design and Construction, etc) Regulations 1996*[ciii] apply to all wells drilled with a view to the extraction of petroleum regardless of whether it is onshore or offshore. These specify that the operator should ensure that there can be no unplanned escape of fluids from the well. Other regulations and guidance on well integrity and pressure management include *The Borehole Sites and Operations Regulations 1995*, the *Oil and Gas UK Well Life Cycle Integrity Guidelines*[civ], UKOOG's *UK Onshore Shale Gas Well Guidelines*[cv] and various API recommended practice[cvi].

Responsibility for the monitoring of well integrity, and ensuring the competence of those doing so, lies with the well operator as duty holder. There is also an independent well examiner. Monitoring of well operations during construction are based on weekly operations reports submitted to HSE by the well operators to ensure the construction matches the design, alongside both planned and subject to ad-hoc site inspections. The HSE's role is one of sampling to verify that regulations are complied with and taking appropriate enforcement action where they are not. The HSE is normally just concerned with the human health impact, but in the case of hydraulic fracturing it insists on well designs that will ensure no unplanned release of fluids, so this also serves to provide environmental protection as well.

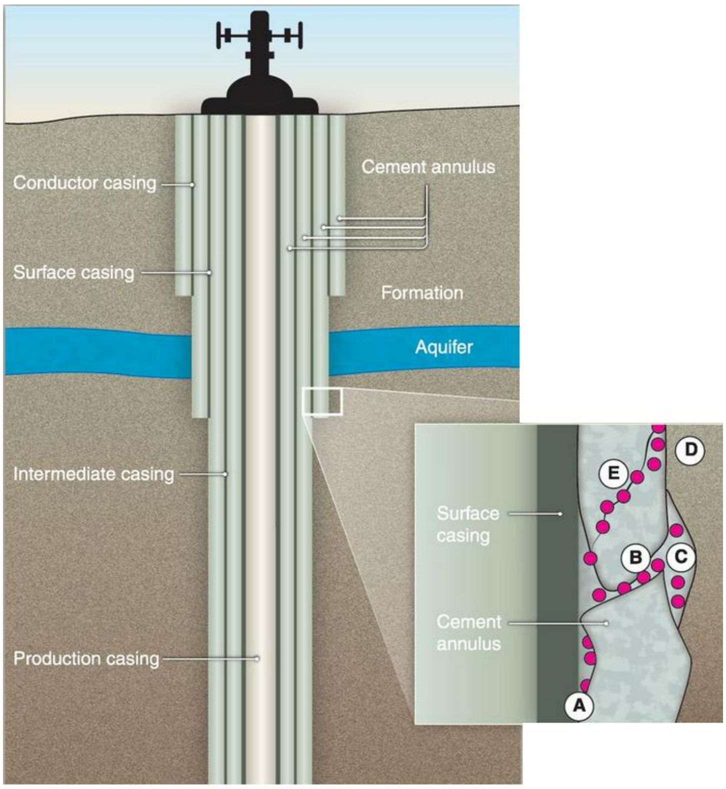


Figure 3.7 Shale well and potential for cement failure (not to scale)[cvii]. A - between cement and casing; B - through fractures; C - through gaps; D - between cement and formation; E - through cement.

It is important to distinguish between well failure and barrier failure. A failure can refer to the failure of any barrier element within a multiple barrier system and is reported to the appropriate regulatory agency[cviii]. Failure to pass a barrier test does not mean that a leak to the surrounding environment has or will occur and rigorous well testing and monitoring can help to identify any potential problems that can then be remediated[cix].

Contamination of groundwater due to the mobilisation of solutes or methane

Another concern is from the potential contamination of groundwater from the mobilisation of solutes or methane as a result of the fracturing process deep underground. Due to the much greater depths at which some UK shales are likely to be exploited (now below at least 1000m) compared to the US, there is less risk to groundwater from the mobilisation of solutes or methane as it would have to migrate through many hundreds of metres and many layers of rock to reach a freshwater aquifer. In SPZ1 and in protected areas further regulations[cx] provide an extra buffer, restricting hydraulic fracturing to below 1200 metres.

The new regulations to restrict hydraulic fracturing to 1000 and 1200m should provide a reasonable buffer to protect from mobilisation of methane and other contaminants. CIWEM previously recommended a depth of 1500m in-line with the advice of the BGS[cxi] and where there is a complex relationship between the shale and the aquifer a site specific assessment should be undertaken. We welcome the new requirement for a hydrogeological risk assessment by an expert and it should be for them to demonstrate that there is no connectivity. Outside of the restricted areas and SPZ1 the risk of contamination from the loss of well integrity still requires consideration.

To achieve OGA approval, operators will have to produce a hydraulic fracture plan and the agreed method for monitoring before, during and after operations. The hydraulic fracturing plan should include the proposed design of the fracture geometry including target zones, sealing mechanism and the location of aquifers, so as not to allow fracturing fluids to migrate to groundwater. Fracturing operations should be monitored using performance standards, these will be well-dependent but might include microseismic and tiltmeter monitoring of hydraulic fracture growth.

Monitoring for methane

Methane is a common trace component of groundwater so the presence of methane in an aquifer is not proof of contamination. Methane in groundwater is formed by one of two processes: biogenic and thermogenic. Biogenic methane is bacterially produced and is associated with shallow anaerobic environments (e.g. peat bogs, wetlands) and is generally the most common form of methane detected in shallow groundwater. Thermogenic methane is formed from thermal decomposition of organic matter at depth and under high pressures and is often associated with coal, oil and gas fields. Conventional natural gas is thermogenic gas.

In the UK most methane in groundwater is likely to be biogenic in origin, although thermogenic contributions may be locally important where gases have migrated from depth or there is slow release from previously deeply buried, low permeability, organic-rich rocks[cxii]. The depth of shale gas extraction makes it difficult to track and attribute pathways of contamination of groundwater from the extraction process. However biogenic and thermogenic methane have different characteristics so dissolved gas and stable isotope analysis of groundwater samples can be used to identify the different sources and potential origin of methane.

The BGS has undertaken a national baseline survey of methane, covering all prospective areas for shale gas in England and Wales with the summary results published in 2015[cxiii]. These surveys will enable environmental regulators to understand background methane levels prior to assessing permit applications and provide a baseline from which any future changes can be measured. The BGS is also undertaking comprehensive baseline monitoring at two proposed sites in Lancashire and one in Yorkshire where planning applications have been submitted for hydraulic fracturing[cxiv].

Risk of contamination from flooding

There is a risk based approach in the planning system to prevent shale gas operations in areas of flood risk. Local planning authorities' Strategic Flood Risk Assessments will assess the risk to an area from flooding from all sources (including rising groundwater and from 'artificial sources') to inform land use planning. A site-specific flood risk assessment is required for all developments in areas where flooding is an issue, and for all development sites of at least one hectare. The environmental regulators can also incorporate conditions into a site's environmental permit to ensure that flood risk is managed appropriately.

Surface water flooding may need to be a greater consideration where climate change suggests more extreme weather events. A surface water drainage system is necessary to ensure controlled waters are not polluted and this should be detailed to the Environment Agency. The applicant should include construction details, including the design of tanks and reference to how ditches will be lined. They should also provide rainfall and runoff calculations to demonstrate that the drainage system can accommodate storm events. This is relevant because if the drainage system or tanks are inadequate and become surcharged, it could lead to contaminated surface water running off the site. In the event that a discharge is proposed, further information and an appropriate permit application will be required. For example, the Roseacre Wood planning application states that the site will collect storm water and remove it by tanker.

Should a site be near a main river, flood or sea defence then a Flood Defence Consent will be required from the environmental regulator.

Management of flowback and produced water

Flowback and produced water are the waters which flow back up the well following the hydraulic fracturing process. Water initially collected from the well after hydraulic fracturing which contains a high proportion of hydraulic fracturing fluids is often called flowback, any formation water returning to the surface is referred to as produced water. In practice it may be difficult to distinguish between the two so the waters are collectively referred to as returned waters.

The quantity of the returned waters will vary from well to well and will relate to the amount that was used in the fracturing process. Flow rates are generally high initially, and then decrease over time throughout oil or gas production. Typically between 20-40 per cent returns to the surface in the first few days to a week, and is stored in holding and treatment tanks[cxv]. This relatively low proportion in comparison to the volume initially pumped down the well is due to the desiccated nature of shale, which absorbs much of the initially injected water. Of the water that remains underground, much of it returns to the surface, up the bore with the gas, over the lifetime of the well at a slower flowrate. Returned waters can be up to 80 per cent of the volume pumped into the ground.

Initially the water is similar to the hydraulic fracturing fluid containing a proportion of the proppants and lubricant substances which were added prior to fracturing. As time goes on the composition is affected by the characteristics of the formation and possible reactions between the formation and the fracturing fluid. This may include a range of organic and inorganic substances in solution or suspension, including heavy hydrocarbons, naturally occurring radioactive materials (NORMs) and a range of minerals and salts representative of the geology. Returned waters are another potential source of contamination, be that to soil, surface or groundwater from spills and will need to be treated and disposed of safely.

Under the EU Mining Waste Directive[cxvi] and Environmental Permitting Regulations[cxvii] (EPR) every onshore oil and gas operation will require a permit for the management of extractive waste from the environmental regulator as the wastes are classified as mining (or 'extractive') waste. A standard rules permit has been developed for the management of waste generated from onshore oil and gas prospecting activities without well stimulation[cxviii]. Any activities that fall outside of this will require a bespoke permit. This is required to cover the wastes produced including drilling muds, cuttings, waste cement, proppants, waste gases, flowback fluid and produced waters.

Sites will be required to produce and implement a Waste Management Plan. This will need to state the characteristics of each waste (inert, non-hazardous non-inert, or hazardous) and the estimated total quantities of extractive waste that will be produced. It will also need to consider how waste can be reduced and its harmfulness and any subsequent treatment of each waste should be indicated. There will be additional requirements if waste is accumulated on-site or if hydraulic fracture fluid is left underground.

The Waste Framework Directive[cxix] sets out what is waste, how it should be managed and how to identify whether it is a hazardous waste. The Environment Agency's onshore oil and gas sector guidance[cxx] provides further details on permit requirements and waste codes which describe how and where (on or off-site) the wastes should be treated. If wastes are found to contain a sufficiently high concentration of radioactive material, the site will require a Radioactive Substances Regulation (RSR) permit under Schedule 23 of the EPR. The Environment Agency expects that any activity that produces gas will require a radioactive substance permit. Where this is not the case wastes will need to be assessed against the threshold concentrations in the EA's hazardous waste guidance[cxxi] and Defra's guidance document[cxxii]. Disposal routes must be through appropriately permitted facilities.

Storage

It is likely that storage of returned waters would only take place whilst flowback and produced water are being treated on-site for re-use or awaiting collection for transportation to an appropriate treatment works. Guidance from the EA states that storage of flowback fluid should be for as short a time as is reasonably practical and should be indicated in the site's waste management plan[cxxiii]. In the future there may be more need for on-site storage as water resource issues and treatment capacity could present issues from downtime.

It has been common practice in the US to store flowback and produced water temporarily on-site in specifically constructed containment ponds. However due to concerns over the release of fugitive emissions and for pond liners to leak, the Environment Agency's draft technical guidance explicitly prohibits the use of open lagoons for storage of produced water and fully contained transfer and storage systems must be used. Where there is radioactive wastewater it must not be stored for more than three months and there should be a contingency plan and equipment to minimise the impact of any spills. When operators apply for their permit they will have to demonstrate Best Available Techniques in the design and operation of the facility. This will then be inspected once operational[cxxiv].

If more than 200 tonnes of crude oil (any hydrocarbon that is extracted from a mineral well that is liquid at ambient pressure and temperature) then the Control of Major Accident Hazard Regulations (COMAH) may also apply.

Transportation

Spills or leaks could potentially occur during the transportation of returned waters that require treatment. Preventative measures should be included in the waste management plan. If the waste is determined to be hazardous, those involved in its transportation must be a carrier licensed by the EA to transport hazardous or industrial wastes and undertake it in appropriate tankers. The levels of waste arising will have to be assessed against the Carriage of Dangerous Goods regulations[cxxv]. Shale gas operators are keen to develop on-site treatment processes so that they reduce the risks associated with transporting hazardous waste.

Reuse

Reuse of flowback and produced water arguably represents the most sustainable process in terms of water resource use. On-site treatment processes also reduce the risks associated with transporting waste. The Environment Agency's draft sector guidance[cxxvi] indicates where this may be appropriate, and distinguishes between flowback and produced water.

Flowback fluid can be treated and re-used as fresh injection fluid for hydraulic fracturing. The treatment would have to take place on site to comply with the European Mining Waste Directive. However reinjection of flowback fluid for disposal will not generally be permitted.

It may be possible where it is re-injected into formations from which hydrocarbons have been extracted and will have no impact on the status of water bodies or pose any risk to groundwater. Flowback fluid that is not suitable for reuse is classed as a *waste* and must be sent to an appropriate permitted waste facility for treatment or disposal.

Produced water can be reinjected to facilitate production if the appropriate groundwater and radioactive substance permits are in place. It can also be re-injected for disposal if the produced water contains a concentration of NORM waste above the out of scope[cxxvii] values, as this minimises public exposure to ionising radiation. Where it is below the out of scope NORM waste values it can be re-injected for disposal at the original site under a groundwater permit. Re-injection at another site can also be permitted in certain circumstances.

Since re-injection for disposal has been thought to cause induced seismicity in the US, CIWEM considers the risks from contamination or induced seismicity must be adequately assessed for any re-injection activity through the groundwater permit and hydrogeological assessment. The Environment Agency's final guidance is expected in 2016.

Treatment

The nature of the substances concerned mean that the water may not be of an appropriate chemical composition to be sent to a typical wastewater treatment works and may require specialist industrial treatment or pre-treatment in order to enable this. It may be highly saline and contain NORMs but the exact composition, pH and other characteristics will vary depending on geological characteristics as well as timing. Flowback associated with the initial fracture may contain higher concentrations of chemicals than the latter produced water which reaches the surface together with the gas during the production phase.

It is the responsibility of shale gas operators to undertake laboratory and batch scale trials of these wastewaters and ensure that they are disposed of through an appropriately licensed facility. As noted operators may be able to re-use a proportion of the wastewater on-site, with disposal of any solids and effluent to an appropriately licensed treatment and disposal facility. Otherwise treatment of effluents and extractive wastes can be removed from site, either via constructed pipeline or tanker, to an appropriately licensed treatment and disposal facility.

The Environment Agency considers the techniques described in the *Common waste water and waste gas treatment in the chemicals sector best available techniques reference document (BREF)*[cxxviii] to be BAT[ii] for treatment of effluents from onshore oil and gas operations. Effluent streams should be recycled wherever possible[cxxix].

Assuming that the contaminant profile of flowback and produced water is appropriate for treatment at a wastewater treatment works, a local water company should be willing to receive it if they had the right permits in place. Wastewater that does not contain NORM will

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[ii] Where Best Available Techniques are enshrined in an EU BAT Reference (BREF) document then it has a legal status. In guidance alone, BAT does not have a legal status but it is still a requirement for operators to demonstrate that they have assessed using it.

not pose a technical problem and the only issue will be the cost of treatment. There is guidance on the scope and exemptions from the radioactive substances legislation[cxxx]. If NORM is at a level that requires a facility to have the requisite permit, then this could question the financial viability of hydraulic fracturing from that particular site. There are standard rules for the disposal of NORM waste.

There may also be issues around the salinity of the waste as this has adverse effects on biological treatment processes in operation at most wastewater treatment plant. Water companies will have to balance the costs of permitting and compliance for receipt of NORM and a highly saline waste against the benefits of increased business. Shale gas operators will need to inform water companies over the volumes and timescales of discharge so they can calculate if the waste can be accepted. If a water utility was unwilling to receive wastewaters containing NORM, then it would need to be sent to a more specialised industrial wastewater treatment plant.

Thermal processes and reverse osmosis have been the most common treatment processes in the US and Australia[cxxxi]. Other options are available but can rapidly increase the energy used in treatment. The US has benefited from less stringent environmental regulations in some states where wastewater is allowed to be injected underground for disposal making the process much more economically viable rather than having to undertake expensive treatment technologies. The easiest option to treat a highly saline waste in the UK would be to use a treatment works that discharges into an estuary to reduce the need for dilution. It may be cheaper to transport the material to such a treatment plant, rather than undergo expensive salinity reduction before discharge into a freshwater receiving watercourse (depending on how far the site is from an estuary). Although there is an added health and safety risk from transportation and an increased social nuisance from truck movements.

Concern has been expressed about experiences in the US with some municipal treatment works having significant problems coping with both the volume and chemical composition of wastewaters[cxxxii]. At the exploration stage there does not appear to be such concern within the UK as there are water company treatment works with the capacity to cope with a range of contaminants and a number of industrial wastewater treatment works. Similarly, a support industry for the management of wastes specifically associated with the offshore oil and gas industry indicate that treatment capacity should not represent a problem. If treatment and disposal capacity is restricted or temporarily unavailable then wells can be temporarily suspended. As the industry grows a supply chain will also have to grow to support it.

The main implication for the shale industry is the overall financial cost of compliance with the UK and EU's robust water regulation regime. Due to the tightening of Radioactive Substances Regulation limits the waste may need to be transported further for treatment which would increase costs in addition to the further cost to treat waste to a higher standard. There is very little disposal capacity at present for non-nuclear radioactive waste, which is normally considered to be Very Low or Low Level Radioactive Waste. This might elevate risk considerations where additional storage and transport are required.

Decommissioning of shale gas wells

Following production, the wellhead will be removed and the casings cut and sealed to three metres below the ground. Wells must be properly closed with cement plugs and/or mechanical barriers in the wellbore to seal any permeable layers and to eliminate the pathway to the surface or freshwater sources. This will also reduce the risk from a new nearby well connecting to an existing wellbore and providing a pathway for contamination.

The well must be decommissioned in accordance with the *Borehole Sites and Operations Regulations 1995*, the *Offshore Installations and Wells (Design and Construction etc.) Regulations 1996*, the PEDL licence and the Oil and Gas UK Guidelines for the suspension and abandonment of wells. The process will be reviewed by an independent well examiner and the HSE. Environmental permits will need to be surrendered to the Environment Agency.

In restoring a shale gas site there will need to be suitable decommissioning materials for the entire length of the well and an appropriate methodology to provide assurance that cross-contamination of different aquifers (particularly in the long term) will be prevented. As boreholes pass through different geologies, at great depths, the groundwater conditions have the potential to vary greatly. UKOOG recommend using a completed borehole log (a record of the actual geology of the exploration borehole as drilled), rather than a prediction of the geological layers. This enables a better design of the restoration phase to protect the groundwater environment.

A site condition report is required by the Environment Agency throughout the lifetime of the permit. At the end of the well's life, the operator will have to show that there has been no significant deterioration in the condition of the site and where the regulator has cause for concern there may need to be further site remediation and / or post decommission monitoring[cxxxiii].

4. Discussion & Conclusions

Viability of commercial shale gas development in the UK

Whilst there has been much speculation on both sides of the shale gas discussion as to whether an industry might be viable, without further assessment neither the industry nor the government have the information to make a meaningful estimate of recoverable reserves at the current time. The discrepancies evident between the projections made by opponents and proponents underline the requirement for clear scientific evidence and transparency to be at the centre of the debate.

If we take the assumption that exploration is successful, production is still unlikely to make a meaningful contribution to the UK's domestic natural gas supply until the 2020s. The drilling intensity required to achieve this level of production may be limited by resource access, technology, the regulatory framework or market access. Provided there is a suitable resource, the technology does exist to extract it and future technological advancement should help to bring down costs by increasing the efficiency of wells. What will be needed however is growth of service sector capacity for the supply chain, for example in wastewater treatment capacity and alternative treatment technologies.

Two years on from CIWEM's initial report little progress has been made in terms of wells drilled, and this has been largely from delays and rejections to planning applications. However this has been of benefit as in the interim there has been time for the industry to collaborate and develop guidelines, whilst the regulators have streamlined regulation with standard rules and developed guidance and best available techniques to minimise environmental harm. Baseline data has also started to be collected. New legislation has also increased environmental protection with the restriction of hydraulic fracturing to over 1000m below the surface, the proposed ban on surface developments and restricted it to a depth of 1200 metres in protected areas and Source Protection Zone 1.

CIWEM welcomes the work undertaken by the regulators and believes that as the industry develops guidance should be kept under review. Further work to establish best available techniques will also be needed. Should the industry see successful exploration and reach the development stage, regulations may need to be modified to reflect the more intensive conditions associated with it. It is absolutely imperative that the Government continues its commitment to a tightly controlled industry and ensures that the regulators are properly resourced to undertake their duties.

The law firm Bird and Bird notes the UK has one of the most pro-shale administrations in Europe, with only Poland to rival it[cxxxiv]. DECC to its credit has improved levels of social understanding of the process, industry, risks and safeguards which CIWEM had previously been critical of. The Department has expanded its portfolio of public facing information which now includes an extensive FAQ document, videos, fact sheet[cxxxv] and regulatory roadmaps[cxxxvi]. This is welcome and DECC with the industry's various regulators, should continue with this public engagement.

Although the government has tried to speed up the planning process, this remains the greatest barrier to the quick development of an extensive industry. Active public opposition groups have the potential to challenge local authorities and could lead to a difficult public relations situation for the government and the shale gas industry. There has already been a widespread emergence of local opposition groups, even in areas where there has been little realistic indication of future shale gas exploitation. It is evident in this that there is significant mistrust of the industry and its ability to operate at low levels of risk.

Mistrust may be amplified by poorly implemented public consultation processes in some areas of shale gas exploration to date. UKOOG and shale gas operators have talked confidently of involving communities. During 2014 the industry engaged in over 90 community meetings and conversed with more than 6,000 local people. The industry clearly realises it needs to establish a social licence to operate and this level of activity is welcome and will need to be maintained until the industry is able to prove itself.

The Government's move to call-in planning applications (through a recovered planning appeal or through the Planning Act regime[cxxxvii]) will do little to inspire confidence from local communities. The Roseacre Wood planning application in Lancashire was rejected for legitimate reasons due to a severe impact on road safety from HGVs, not on ideological grounds. To overturn such a decision without mitigating these concerns would go to harm public trust and ultimately the industry.

Another aspect of public acceptance is the question of where shale gas fits into our overall energy policy. The strategic lead role for gas must also be set within clear decarbonisation targets and alongside renewable energy and energy efficiency policies. Reducing levels of fugitive emissions will need to be resolved alongside investment in the development of carbon capture and storage. Progress on achieving these outcomes is very limited at the present time.

	2014 Recommendations	Progress
1	**Government departments and agencies should actively promote informed understanding among stakeholders using clear scientific evidence, transparency and consistent messages, across a range of media and forums. Government Ministers should ensure that their messages on shale gas are consistent with those of the departments.**	The relevant Government departments and agencies have made considerable progress to improve public understanding. DECC and the regulators have produced a wealth of material and guidance to this aim. However there is still some inflammatory language being used by some senior Parliamentarians. A series of Government 'u turn' announcements on protected areas has undermined some public trust, although generally the outcome has been welcomed as improving environmental protection. The change to allow the intervention of Secretaries of State in determining planning appeals is likely to cause deepened public concern with the erosion of localism.

2	**The industry should ensure it complies with the UKOOG community engagement charter so that the public are involved within the planning process with adequate notice and information. The production of guidance for local communities on what they can expect and where they can and cannot influence would be helpful.**	The industry, through UKOOG, has committed to conducting early stage environmental risk assessments to be discussed with local communities and Environmental Impact Assessments associated with sites that include hydraulic fracturing. These commitments have been put in place for planning applications submitted for three sites in Lancashire and North Yorkshire. Yet public opposition in these areas remains strong. Building public trust is still a key issue for the industry to ensure it has a social licence to operate. UKOOG has also published further guidelines for the industry on addressing public health and establishing environmental baselines which will be helpful in building the integrity of the industry.
3	**Further collaboration between the agencies involved in advising and regulating the industry is required. As regulation is developed for the appraisal and production phases, a rationalised and integrated system of risk assessment should be included to avoid confusion, increase public engagement and reduce delays.**	The Oil and Gas Authority has been set up as an executive agency of DECC, although regulatory responsibility still sits between a number of agencies. It is possibly too early to assess the work of the OGA and how it will work with the others involved in regulation. The Environment Agency is working on sector guidance for permitting and best available techniques for the industry where these are available. It has also established standard rules permits to reduce delays. The industry has produced draft guidelines on Environmental Risk Assessment and Environmental Impact Assessment, which it expects to complete in early 2016. These should be independently scrutinised to ensure that they adequately protect health and the environment.

Assessment of risks to water resources

There has been a wide variation in the estimates of water use in the different stages of shale gas production, but this still allows certain conclusions to be drawn. The key question will be how many wells there will be in a given area and over what timeframe they will be drilled and fractured?

At the exploration stage water demand is not likely to be significant compared to other users and it is likely that operators will continue to source water on a site by site basis depending on the closest source and ease of connectivity. Should a large industry develop in a small geographic area there could be local or regional consequences. As the water use is 'front loaded' for a short period of time at the beginning of the life of a well, there could be local impacts for catchments and water sourcing for the industry may require a certain element of temporal planning.

Claims by some opponents that the shale gas industry represents a threat to the security of public water supplies are alarmist. The industry will have to compete against different users and should there be any temporary water use restrictions put into place, it could in theory be affected. Taking a regional scenario the water required by the industry is comparable to other industrial users and would face the same drought restrictions.

If water companies have the available resources and there is a close mains connection this is possibly the easiest option; tankers may also be used. Operators can also source their own water from the environment either via borehole or direct abstraction from a watercourse should the Catchment Abstraction Management Strategy deduce that there is spare water.

Where there is overlap between water stressed catchments and shale gas licence areas, operators will need to be aware of the risk that there may be smaller volumes available in the future. Drilling and fracturing processes may have to be timed as to when volumes of water are available. Early engagement with the Environment Agency or local water company, depending on where the water is sourced, will be important to ascertain available volumes. CIWEM considers companies should continue to work to improve the accuracy of their water consumption and production estimates and communicate these with water companies.

	2014 Recommendations	Progress
4	**CIWEM believes water and sewerage companies should become statutory consultees in the shale gas planning process regardless of whether they continue to provide and treat water for the industry. They must be engaged with early and provided with the right information to meet their duties.**	It is welcome that this has been recognised and progressed through the *Infrastructure Act 2015* and implemented in *The Town and Country Planning (Development Management Procedure (England) Order 2015*. It will now be for shale gas and water companies to build relationships and make sure that this is put into practice, particularly as the industry moves into the production phase.

Assessment of risks to the water environment

The impacts of shale gas extraction on water and the local environment are likely to be local, dependent on whether the location of any productive areas of geology coincides with areas of particular water resource pressure and/or near to groundwater resources or sensitive aquatic environments.

CIWEM believes that if shale gas is to be developed safely, ensuring due regard for protection of the wider environment, exploration should not be permitted in areas where there is a genuine risk to valuable drinking water resources located in groundwater. It is welcome that environmental regulators will not allow any drilling in source protection zone 1 to a depth of 1200 meters and that elsewhere it will refuse permits where there is a risk to groundwater. This should provide a reasonable buffer to protect from mobilisation of methane and other contaminants although CIWEM previously recommended a depth of 1500m.

Groundwater including any local aquifers should be carefully delineated by the operator as part of the well design and fracturing risk assessment process. CIWEM previously called for a thorough evaluation of geological and hydrogeological setting by a suitably qualified geologist to be undertaken by the operator and scrutinised by the Environment Agency, who could place conditions such as a maximum fracture growth height. We welcome that this proposal has been adopted by the Environment Agency which requires a hydrogeological assessment to be undertaken and carried out by a suitably qualified person in its latest draft guidance. This should detail the faults and existing seismicity and indicate how monitoring will take place.

Loss of well integrity has been recognised as one of the pathways of contamination to groundwater quality and must be seriously considered by all appropriate regulators with construction closely monitored to ensure that best practice is followed. The HSE must undertake an active role in visiting sites for verification inspections of monitoring operations and take enforcement action where it is found to be inadequate.

Contamination of soil, surface or groundwater from spills of returned waters is a considerable hazard. Risk assessments need to consider all potential sources of pollution, potential pathways and receptors. Evidence from the US suggests that the maintenance of well integrity, including post operations, and appropriate storage and management of fracturing fluids and wastes are important factors in controlling risks[cxxxviii]. Massachusetts Institute of Technology reviewed[cxxxix] 10,000 wells and found that of 43 pollution incidents related to natural gas operations, 50 per cent were related to the contamination of groundwater due to drilling operations and 33 per cent due to surface spills of stored fracturing fluids and flowback water. Best available techniques will need to be applied to ensure returned waters are appropriately contained, managed, and treated prior to eventual disposal.

Accurate baseline environmental monitoring is essential to assess the impact of shale gas extraction on the environment and any implications for public health and should begin immediately. In both Australia and the US, where the regulatory framework developed at the same time as the industry, no environmental baseline was established which has led to what amounts to conjecture on both sides of an extremely polarised debate. Good data, measurement, and transparency by the industry are vital to environmental protection and public trust. CIWEM welcomes the study by the BGS to assess baseline levels of methane in groundwater. Along with partners, the BGS is also undertaking a project partly funded by government to establish the environmental baseline at two Cuadrilla sites in Lancashire and in the Vale of Pickering, Yorkshire. This comprehensive study will measure air quality, surface-water quality, soil gases, seismicity and ground motion.

Following the production of a baseline, the long-term monitoring of relative conditions will be required. This should be carried out throughout the lifetime of development, production and post-production.

	2014 Recommendations	Progress
5	**The importance of baseline monitoring cannot be overstated. Regulators must ensure that an environmental baseline is fully established before any commencement of drilling activity and this should include both deep and shallow aquifers for radio-nuclides and other contaminants. Full details of the environmental monitoring programme should be disclosed.**	The British Geological Survey has completed a national baseline methane survey and is undertaking comprehensive baseline monitoring at two sites in Lancashire. It is welcome that this is independent from the industry and the findings should be used to update baseline monitoring guidelines and used at all sites in the future. Draft Environment Agency guidelines set out that a site condition report is required before commencement of operations. UKOOG published baseline monitoring guidance for soil, air and water before and during operations in 2015 with which all of its Members must comply.
6	**The long-term monitoring of relative conditions to the environmental baseline in the vicinity of the well and nearby receptors throughout the lifetime of the well will be important to detect any contaminants. In developing production guidance, parameters on the frequency, locations and time scale of measurements should be included.**	The *Infrastructure Act 2015* requires appropriate arrangements for the monitoring of emissions of methane into the air for the duration of the permit. The Environment Agency has produced draft guidance for operational monitoring on a wide range of aspects. It considers it best practice to undertake groundwater monitoring even if it not required by a permit. The BGS comprehensive baseline study should be used as a strong evidence base against which to any future changes in environmental condition can be assessed and future monitoring programmes designed.
7	**The protection of groundwater must be made a priority and the environmental regulator should continue to adopt the precautionary principle where there is insufficient certainty to protect groundwater. Operators should provide the environmental regulator with a detailed risk**	The *Infrastructure Act 2015* prohibits hydraulic fracturing anywhere at a depth of less than 1000 metres. New provisions set out in the *Onshore Hydraulic Fracturing (Protected Areas) Regulations 2015* restrict hydraulic fracturing to take place below 1200metres in Source Protection Zone (SPZ) 1. This should provide a reasonable buffer to protect the groundwater from contamination by methane and other contaminants, although a more effective

assessment to examine the relationship between the shale and the aquifer including a thorough evaluation of geological and hydrogeological setting.

requirement may be for the operator to demonstrate that there is no connectivity. It is welcome that the Environment Agency now requires the completion of a hydrogeological assessment to be undertaken by a suitably qualified person in its latest draft guidance.

Outside of the restricted areas the risk of contamination from the loss of well integrity still requires consideration.

Best available techniques will need to be applied by operators to ensure returned waters are appropriately contained, managed, and treated prior to eventual disposal. CIWEM considers mismanagement is one of the greatest risks for contamination of the environment

Assessment of risks associated with water treatment

The returned waters from the hydraulic fracturing process will require treatment dependent on whether or not they are being reused and for their intended disposal pathway. The nature of the substances concerned mean that the water may not be of an appropriate chemical composition to be sent to a typical public wastewater treatment works and may require specialist industrial treatment or pre-treatment in order to enable this. They may be highly saline and include naturally occurring radioactive materials. This presents further financial and regulatory risk to meet compliance with the UK's robust water regulation regime.

At the exploration stage there seems to be enough capacity to treat returned waters as public treatment works are able to cope with a range of contaminants and there are a number of industrial wastewater treatment works in the UK. However returned waters are likely to be highly saline and to be able to treat by dilution a public treatment plant that discharges to an estuary may be needed. There are other technologies available but these entail greater energy consumption and cost. It is certain that if the industry grows, and wastewater volumes increase, water treatment capacity will need to expand to support it. There also needs to be further consideration given to disposal of the solid residues from some treatment options.

Reuse of flow back and produced water arguably represents the most sustainable process and the regulatory systems should aim to encourage this. The development of onsite treatment processes will also reduce the risks associated with transporting waste.

	2014 Recommendations	Progress
8	**Further research is needed into hydraulic fracturing with lower quality waters and also waterless techniques to minimise water use and thus requiring less subsequent treatment.**	The service industry continues to work on lower water quality solutions internationally. The UK should identify what it can learn from this, particularly as the industry enters the production phase.
9	**Research and development is needed in water treatment and decontamination technologies that exhibit reduced energy consumption, as well as into onsite and mobile treatment solutions that reduce the risks of transporting waste.**	The Natural Environment Research Council in the UK and the United States National Science Federation are jointly looking at scientific and technological innovation to improve understanding and mitigate potential environmental impacts. There is also work being undertaken by the EU Commission Joint Research Centre in this area. CIWEM, UKOOG, WaterUK and British Water have established an initiative to bring together key stakeholders to consider the whole life management of water issues, including mobile treatment solutions and water sourcing. Most of these initiatives are in their infancy and there is still much to learn from abroad and progress.
10	**The reuse of hydraulic fracturing fluid on site is the preferred option of the industry and the regulator. Given that there is common ground between the industry and regulator, they should work closely together to identify optimum solutions.**	The environmental regulators have been looking to develop best available techniques for the management of flowback fluid and re-injection. The Environment Agency's final sector guidance to be published in early 2016 is likely to suggest that the reinjection of flowback and produced water will be allowed for the purposes of re-fracture. A groundwater permit and in some cases a radioactive substances permit will be required. Re-injection for disposal may be allowed in certain circumstances. CIWEM considers the risks from contamination and induced seismicity must be adequately assessed for any re-injection activity through the groundwater permit and hydrogeological assessment.

Appendix 1. *Infrastructure Act 2015*

Section 50 Onshore hydraulic fracturing: safeguards

After section 4 of the Petroleum Act 1998 insert—

"4A Onshore hydraulic fracturing: safeguards

(1)The Secretary of State must not issue a well consent that is required by an onshore licence for England or Wales unless the well consent imposes—

(a) a condition which prohibits associated hydraulic fracturing from taking place in land at a depth of less than 1000 metres; and

(b) a condition which prohibits associated hydraulic fracturing from taking place in land at a depth of 1000 metres or more unless the licensee has the Secretary of State's consent for it to take place (a "hydraulic fracturing consent").

(2) A hydraulic fracturing consent is not to be issued unless an application for its issue is made by, or on behalf of, the licensee.

(3) Where an application is made, the Secretary of State may not issue a hydraulic fracturing consent unless the Secretary of State—

(a) is satisfied that—

(i) the conditions in column 1 of the following table are met, and

(ii) the conditions in subsection (6) are met, and

(b) is otherwise satisfied that it is appropriate to issue the consent.

(4)The existence of a document of the kind mentioned in column 2 of the table in this section is sufficient for the Secretary of State to be satisfied that the condition to which that document relates is met.

(5)But the absence of such a document does not prevent the Secretary of State from being satisfied that that condition is met.

Column 1: conditions		*Column 2: documents*
1	The environmental impact of the development which includes the relevant well has been taken into account by the local planning authority	A notice given by the local planning authority that the environmental information was taken into account in deciding to grant the relevant planning permission
2	Appropriate arrangements have been made for the independent inspection of the integrity of the relevant well	A certificate given by the Health and Safety Executive that it— (a) has received a well notification under regulation 6 of the Borehole Sites and Operations Regulations 1995, (b) has received the information required by regulation 19 of the Offshore Installations and Wells (Design and Construction, etc.) Regulations 1996, and (c) has visited the site of the relevant well

3	The level of methane in groundwater has, or will have, been monitored in the period of 12 months before the associated hydraulic fracturing begins	An environmental permit has been given by the relevant environmental regulator which contains a condition that requires compliance with a waste management plan which provides for monitoring of the level of methane in groundwater in the period of 12 months before the associated hydraulic fracturing begins
4	Appropriate arrangements have been made for the monitoring of emissions of methane into the air	An environmental permit which contains a condition requiring compliance with a waste management plan which provides for the monitoring of emissions of methane into the air for the period of the permit
5	The associated hydraulic fracturing will not take place within protected groundwater source areas	A decision document given by the relevant environmental regulator (in connection with an environmental permit) which indicates that the associated hydraulic fracturing will not take place within protected groundwater source areas
6	The associated hydraulic fracturing will not take place within other protected areas	A notice given by the local planning authority that the area in respect of which the relevant planning permission has been granted does not include any land which is within any other protected areas
7	In considering an application for the relevant planning permission, the local planning authority has (where material) taken into account the cumulative effects of— (a) that application, and (b) other applications relating to exploitation of onshore petroleum obtainable by hydraulic fracturing	A notice given by the local planning authority that it has taken into account those cumulative effects
8	The substances used, or expected to be used, in associated hydraulic fracturing— (a) are approved, or (b) are subject to approval, by the relevant environmental regulator	An environmental permit has been given by the relevant environmental regulator which contains a condition that requires substances used in associated hydraulic fracturing to be approved by that regulator
9	In considering an application for the relevant planning permission, the local planning authority has considered whether to impose a restoration condition in relation to that development	A notice given by the local planning authority that it has considered whether to impose such a condition
10	The relevant undertaker has been consulted before grant of the relevant planning permission	A notice given by the local planning authority that the relevant undertaker has been consulted

11	The public was given notice of the application for the relevant planning permission	A notice given by the local planning authority which confirms that the applicant for the relevant planning permission has certified that public notification requirements, as set out in a development order, have been met

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