General Certificate of Education
Advanced Level Examination
June 2014

Science in Society SCIS4/PM

Unit 4 Case Study

Preliminary Material

- This Source Material should be opened and issued to candidates on or after 1 May 2014.
- A clean copy of the Pre-released Source Material will be provided at the start of the Unit 4 examination.

A

Information

- This case study source material consists of extracts from five sources (**A**–**E**) on the subject of shale gas and hydraulic fracturing (fracking).
- This material is being given to you in advance of the Unit 4 examination to enable you to study the content of each extract in preparation for questions based on the material in the examination. Consider the scientific explanations and the ideas about how science works that are involved, as well as the issues raised in the sources.
- You may write notes on this copy of the case study source material, but you will not be allowed to bring this copy, or any other notes you may have made, into the examination room. You will be provided with a clean copy of this case study source material, together with one additional source, **Source F**, at the start of the Unit 4 examination.
- You are not required to carry out any further study of the topic than is necessary for you to gain an understanding of the ideas described and to consider the issues raised. You are not required to understand any detailed **science explanations** beyond those outlined in **Sources A**–**E** and those in the *Science in Society* specification.
- It is suggested that a minimum of three hours detailed study is spent on this pre-release material.

Source A: Newspaper article from Metro

Blackpool shale gas drilling suspended after earthquake

Sunday 29 May 2011

Shale gas drilling in Blackpool has been suspended after an earthquake hit the Fylde coast in Lancashire during the early hours of Friday.

A spokeswoman for Cuadrilla, the company carrying out the tests, said drilling was suspended as a precaution following the earthquake, confirmed by the British Geological Survey as the area's second in as many months.

Ranked at an intensity level three by seismologists, the 1.5 magnitude tremor caused no injuries or damage in the areas near Blackpool although local residents reported feeling a slight shaking.

Friday morning's earthquake was smaller than the 2.2 magnitude tremor that struck the Blackpool area on 1 April.

In 2009, worried residents further north in Cumbria, as well as in Lancashire, flooded local police with phone calls as a 3.2 magnitude quake struck the region.

A majority of the 20 earthquakes reported each year happen along the west coast of England and Wales.

However, the largest tremor ever experienced in the UK occurred in 1931 on the east side of the country. Measuring 6.1 on the Richter scale, the quake struck around 60 miles off the coast of Yorkshire in the North Sea. The town of Filey was worst hit with a church spire becoming twisted and chimneys collapsing in Hull. Despite the destruction, no direct fatalities were reported.

Source B: Extract from BBC News website

Fracking: Untangling fact from fiction

By Matt McGrath, Environment correspondent, BBC News, 13 December 2012

The government has announced that it will remove a temporary ban on hydraulic fracturing across the UK.

Fracking, as it is known, is a controversial technique for recovering gas and oil from shale rock. But how concerned should people be about the environmental impacts?

Hydraulic fracturing is widely used across the US to exploit reserves of oil and gas that were once believed to be inaccessible.

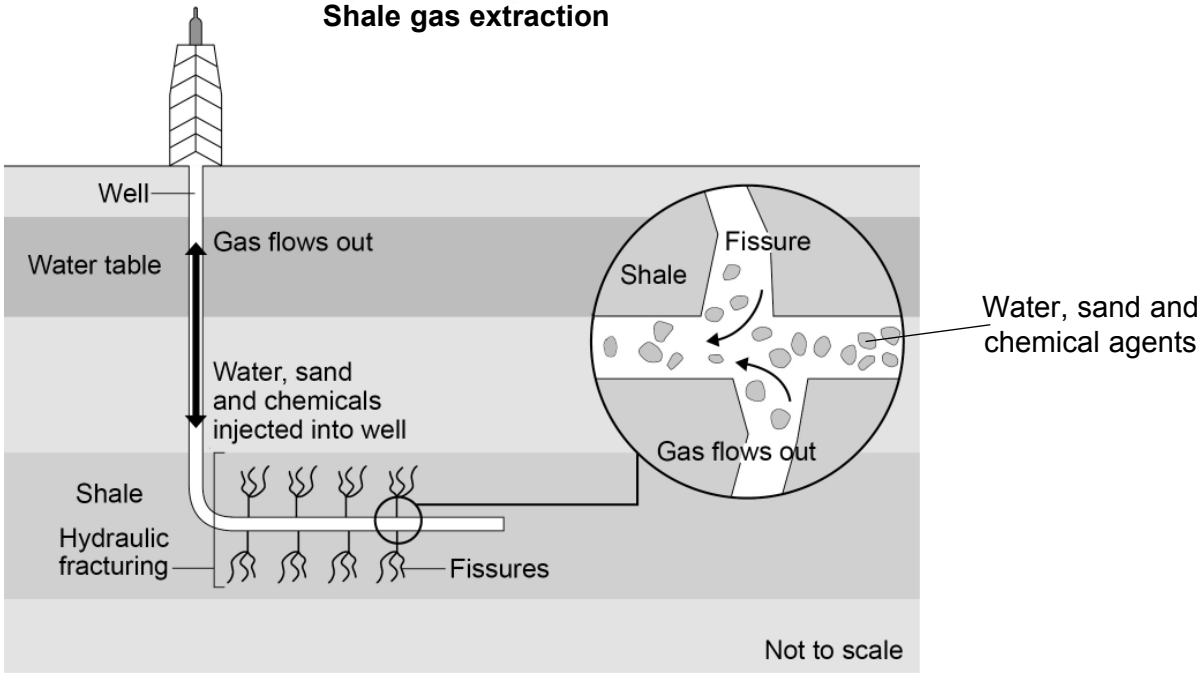
But in the UK, the use of fracking was halted in 2011 after some minor earthquakes near Blackpool, in north-west England, were attributed to test wells being drilled by the energy company Cuadrilla.

The company carried out its own report into the incident and found that it was "most likely" that the seismic events were caused by the direct injection of fluid into the fault zone.

The Department of Energy and Climate Change (DECC) then asked three experts to make an independent assessment. Their report indicated that future earthquakes as a result of fracking could not be ruled out - but the risk from these tremors was low and structural damage extremely unlikely. The experts also made recommendations on how to minimise these risks.

Another review, carried out by the Royal Society and the Royal Academy of Engineering, also gave fracking the green light - provided that strong regulations were in place.

Shale gas extraction



Earthquake issues have also been attributed to fracking in British Columbia, Canada, and in some parts of the United States.

But according to Francis Egan, chief executive of Cuadrilla, there needs to be a sense of proportion about the risk of earthquakes from fracking.

“If you look at the British Geological Survey website, in the last two months alone there were nine events of the same magnitude,” he told BBC News.

“We have a host of measures in place to ensure there is no recurrence.”

It is expected that if fracking resumes in the UK, the government will insist on constant monitoring and a threshold of seismic activity.

If fracking causes a tremor above the limit, it could lead to a suspension of drilling.

Fluid situation

Many people have concerns about the fluid used in fracking. It is normally a mixture of water, sand and some chemicals that is pumped into the well under high pressure to force the gas from the rock.

There have been worries that the fluid is dangerous - suspicions that were fuelled by the reluctance of many companies in the US to disclose what’s exactly in the mixture. Democrats in the US Congress released a report that detailed some 750 different chemicals and other components used in fracking fluid.

In the UK, Cuadrilla has been open about what is in its fracking mixture.

But the liquid going down into the well isn’t the whole story.

Fracking requires tens of millions of litres of fluid - much of what goes down the well comes back up as “produced water”.

It can contain a mixture of organic hydrocarbons, and naturally occurring radioactive material.
In the US, this water is often stored in open pits before it is processed but in the UK the pits will have to be covered.

In many locations where the facilities don’t exist on site, the water has to be trucked away to be cleaned.

Prof Richard Davies, director of the Durham Energy Institute, says that this would also be the likely scenario in the UK if fracking becomes more widespread.

“It’ll be a bit like Pennsylvania, where a whole industry has grown up to deal with waste-water,” he said. “We’ll have to clean the water if we want to re-use it.”

The International Energy Agency (IEA) has suggested ways of cleaning up the water that is used in shale gas exploitation. The IEA says that the technologies to address these issues exist or are in development and if they are adopted, fracking might be more widely accepted.

The other water issue associated with fracking is the potential of the technology to contaminate existing drinking supplies. In the US, the Environmental Protection Agency (EPA) investigated complaints from residents in Pavillion, Wyoming, who complained that fracking was affecting their drinking water.

The EPA's initial report concluded that there was a link with the waste-water produced by drilling for gas. Further investigations into this incident haven't yet conclusively shown the sources of contamination.

There have been many other reports of a similar impact on drinking water from people living near fracking operations across the US.

Prof Davies says that when water has been contaminated in the US it has not been the fault of fracking. It has been as a result of cracks in the wells or surface spillages.

"We have been distracted by hydraulic fracturing," he told BBC News. "It is really at the bottom of the list when it comes to contaminating water supplies. Drilling wells properly and cementing them are the critical things."

In a report published in the journal Marine and Petroleum Geology, Prof Davies found that in the UK the possibility of fracking causing rogue fractures that would allow methane gas to contaminate water was a fraction of 1%.

The study recommended a minimum vertical separation distance between fracking wells and water supplies of 600m (2,000ft).

Some scientists have proposed adding chemical tracers to fracking fluids as a way of confirming that any contamination of drinking water comes from the drilling process.

Environmental disruption

Horizontal drilling can offer many advantages to the gas extraction process, allowing wells to be drilled in several directions from one pad. But there are downsides as well. Horizontal drilling means companies can extract oil and gas from locations that were once inaccessible, and these may be under built-up areas as they are in several cities in the US.

The disruption that this can cause is considerable. Road traffic, drilling noise, and the danger of accidental fuel spillages are all associated with the process.

Mark Boling, executive vice president with Southwestern Energy, a US oil and gas exploration company that uses fracking technology, says the fracking industry needs to be more honest about the real impacts.

"We need to think more innovatively above the ground," he told BBC News. "We need to figure how to do better on surface impacts, water supply, water transfer and disposal, drilling locations - we really didn't come out and say, 'yes, these are risks, and there are obstacles'."

Mr Boling says that in many parts of the US, people have accepted the technology because they have seen a direct financial benefit from selling mineral rights. That's not something that pertains in the UK.

"You are going to have even more difficulty where the minerals are owned by the Crown - if you don't have something that is going to put money in the pockets of people that are suffering through all the trucks, road damage, the compressor noise, all these sorts of things."

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Source C: Opinion article by Andrew Rawnsley from The Observer, 9 December 2012

The fracking dream which is putting Britain's future at risk

George Osborne and fellow zealots believe shale gas to be a bonanza of cheap energy. Where's the evidence?

Amid the inky gloom that shrouded George Osborne when he delivered a wintry autumn statement of more cuts and further tax rises, there was a dreamy gleam in the eye of the Chancellor. Like a Spanish conquistador setting out for Latin America, he thinks he can find a source of fabulous riches. This El Dorado is not made of bullion, but it sounds as good as gold when you hear him and other enthusiasts talk about this magic stuff. It is natural gas in underground shales. For believers, and there are now many of them in the Tory party, shale gas is going to provide Britain with a remarkable bonanza of cheap energy.

Before we go any further, we really need a shorthand phrase to describe them. The process of extraction is called hydraulic fracturing, also known as fracking. Believers in shale gas have a tendency to rave about it as if they are using a mind-bending substance. So I suggest we call them frack-heads.

The Chancellor is the biggest frack-head in the cabinet. Under his influence, the Prime Minister has turned into a frack-head too. Another important frack-head is the Environment Secretary, Owen Paterson. The Energy Secretary, the Lib Dem's Ed Davey, is not a frack-head, but his sensible scepticism about shale gas is increasingly overwhelmed by the zealots at the very top of the government.

The frack-heads think that the "gas strategy" published on the same day will ultimately prove to be much more significant for Britain's future prosperity than anything in the mini-budget. So they were cheered when the Chancellor paved the way for drilling by trailing tax breaks to incentivise the exploration of shale gas and announced a new regulatory outfit, the Office for Unconventional (Shale) Gas, dubbed Ofshag. The belief that a glittering bounty is waiting to be released from those shales is at the heart of a "dash for gas", which envisages up to 30 new gas-fired power stations being built over the next 20 years.

It is easy to see why they get so excited by the thought that there are bountiful quantities of gas just waiting to be tapped under our feet. In the United States, shale gas has been transformative, triggering an energy revolution that has made America virtually self-sufficient in gas and cut prices to about a third of what they are in Britain. At a time when that politicians' favourite "the squeezed middle" are being hit by ever-ballooning bills from power companies, anything that seems to promise cheaper energy is bound to be extremely enticing.

Frack-heads talk feverishly about the reservoirs of shale gas being the equivalent of Britain's share of the original North Sea oil reserves. If that were to prove true, this would indeed provide a rich source of energy for Britain and a big boost to tax revenues for the Treasury. Some Tories even believe that shale gas could do for David Cameron what the black stuff did for Margaret Thatcher. The shale deposits under Lancashire alone, so they claim, could power the country for more than half a century. When they get really carried away, they reimagine Blackpool as the "Dallas of the North" with kiss-me-quick hats swapped for stetsons. Climate-change deniers are prominent among the frack-heads.

Yet it also seems to offer something to greens because shale gas emits half as much carbon dioxide as coal.

Well, it is only human to dream and the temptation to fantasise about miraculous treasures is all the greater if you are a politician looking for relief from many more bleak years of austerity. The trouble with their dream is that it is very risky for Britain.

The way they talk, you might be misled into thinking that shale gas could be drilled today and start flowing tomorrow. The truth is that no one has a clue whether it can be exploited at all, no one will be sure for quite some time to come and, even if it can be profitably tapped, there are very hot arguments about whether it can be done safely. An experimental well operated by the shale gas company Cuadrilla in Lancashire has been suspended since June last year after two mini-earthquakes. The moratorium is expected to be lifted shortly, but the jury remains out on the risks to the environment and human health. The increasingly energetic opposition protest that the process pollutes the water table with toxic and carcinogenic chemicals. This is an issue even in a country as large and relatively empty as the United States. It will be even more so in a country as densely populated as Britain. In France, which is thought to have the second largest potential for shale gas in Europe, the National Assembly has responded to public alarm by banning the drilling of shales. As we report today, concern about the potential hazards of fracking is prompting the European Parliament to try to put the brakes on.

Even if it can be shown to be broadly safe – or at least as safe as any other form of energy exploitation – there will always be occupational hazards to drilling, which include blowouts, explosions and above-ground methane releases. We will see whether Conservative MPs are quite so enthusiastic for shale gas when they have to explain that to their constituents. We will also see how shire Tories take to the prospect of their pretty patches being invaded by huge convoys of juggernauts and disfigured by gas wells. Intensive drilling is incredibly disruptive. In the US, each typical well requires about 1,000 truckloads of equipment and materials. Texans are used to living with that and have long been accustomed to seeing well heads across their landscape. For Britons, this would be an alien experience. Almost all of our current oil and gas platforms are out at sea, far from public view. We cannot know precisely how public opinion would react to parts of Britain beginning to resemble Texas, but we can make an educated guess from how much some people hate the sight of an object as harmless as a wind turbine.

Then there is the huge hole at the heart of the frack-heads' dream. No one even knows yet how much shale gas can be profitably extracted. Estimates of the exploitable reserves vary wildly. In fact, no one can be sure whether it will be viable to get any of it at all out of the ground. Firms are only going to invest in shale gas if they will make some money out of it. That means they will want to be certain that the cost of extraction doesn't make shale gas uncompetitive against alternative forms of gas and other energy sources. Colin Smith, head of energy research at VTB Capital, tells me that there have been some 50 experimental wells across Europe to date. None – not a single one – appears to have flowed at a rate that would make them commercially viable. So while the frack-heads fantasise about a bonanza, the reality is that not so much as one cubic metre of shale gas has been profitably extracted anywhere in Europe.

The explanation is geology. Shales in Europe are generally thinner and deeper, and therefore much more expensive to tap, than those that have been successfully exploited in the United States. And Britain looks likely to be one of the less promising prospects in Europe because its shales are typically among the thinnest.

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You might say that, having taken all the known facts into consideration, the sensible approach is to be sceptical about shale gas while carefully exploring the possibilities in case it proves to have more potential than is currently apparent. That is broadly the position that has been taken by Mr Davey and his department. But they appear to be losing the battle with the shale sect at the top of government who are investing so much hope – and want to throw in taxpayers' money too – in pursuit of fracking.

The risks of this "dash for gas" are multiple. It locks Britain into a continued reliance on an expensive, polluting fossil fuel. Money spent on gas diverts investment from renewables, which is especially bonkers when the green energy sector is one of the few parts of the British economy that is currently displaying good growth. It makes it less likely that we will meet our targets for reducing carbon emissions. Should shale gas truly turn out to be viable, there would be dividends. But if, which seems much more likely at the moment, the claims made for it prove to be false, then Britain is going to be even more exposed to future price shocks and blackmail by foreign suppliers. We are already hazardously dependent on imports from Russia and the Middle East. Much of our gas comes through the Straits of Hormuz from Qatari platforms just outside Iran's territorial waters. I don't know about you, but that doesn't make me feel terribly secure. Nor do I sleep easier at night when I think about Vladimir Putin's finger hovering over our national light switch.

To take so many risks with our nation's future on the basis of such a flimsy dream is – how can I put this politely? – fracking crazy.

Source D: Press release from Department of Energy and Climate Change (DECC)

New controls announced for shale gas exploration

"Shale gas represents a promising new potential energy resource for the UK. It could contribute significantly to our energy security, reducing our reliance on imported gas, as we move to a low carbon economy. "

(Edward Davey)

Press notice 2012/164

13 December 2012

Energy and Climate Change Secretary Edward Davey today announced that exploratory hydraulic fracturing (fracking) for shale gas can resume in the UK, subject to new controls to mitigate the risks of seismic activity.

Mr Davey said:

"Shale gas represents a promising new potential energy resource for the UK. It could contribute significantly to our energy security, reducing our reliance on imported gas, as we move to a low carbon economy.

"My decision is based on the evidence. It comes after detailed study of the latest scientific research available and advice from leading experts in the field.

"We are still in the very early stages of shale gas exploration in the UK and it is likely to develop slowly. It is essential that its development should not come at the expense of local communities or the environment. Fracking must be safe and the public must be confident that it is safe.

"We are strengthening the stringent regime already in place with new controls around seismic risks. And as the industry develops we will remain vigilant to all emerging evidence to ensure fracking is safe and the local environment is protected.

"The new Office of Unconventional Gas and Oil, led by DECC, will be able to focus regulatory effort where necessary to meet the needs of future production.

"Emissions of methane – which is a potent greenhouse gas – are already subject to control, but I am today commissioning a study of the possible impacts of shale gas development on greenhouse gas emissions and climate change."

To date there has been no commercial shale gas production in the UK. Exploratory fracking has been suspended since May 2011 after two small seismic tremors were detected near the country's only fracking operations in Lancashire.

Following a detailed study and further analysis by an independent panel of experts commissioned by the Department of Energy and Climate Change, with feedback from a wide public consultation, and the benefit of the report by the Royal Society and Royal Academy of Engineering, the Government has concluded that the seismic risks associated with fracking can be managed effectively with controls.

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New controls to mitigate seismic risks announced today include:

- a prior review before fracking begins must be carried out to assess seismic risk and the existence of faults
- a fracking plan must be submitted to DECC showing how seismic risks will be addressed
- seismic monitoring must be carried out before, during and after fracking
- a new traffic light system to categorise seismic activity and direct appropriate responses. A trigger mechanism will stop fracking operations in certain conditions.

These controls, along with the rest of recommendations in the independent report into seismic activity and fracking commissioned by the Government and published in March this year, have been accepted by the Secretary of State.

The Secretary of State has also accepted all the recommendations of the Royal Society report which are relevant to Government. (One further recommendation is being considered by the Research Councils.)

The study of the possible impacts of shale gas development on greenhouse gas emissions and climate change will consider the available evidence on the lifecycle of greenhouse gas emissions from shale gas exploitation and the need for further research.

Tony Grayling, Head of Climate Change and Communities at the Environment Agency, said:

“The Environment Agency takes the potential risks arising from fracking for shale gas extraction very seriously and has undertaken a thorough assessment of them.

“We are satisfied that existing regulations are sufficient to protect people and the environment in the current exploratory phase. We have also established a Shale Gas Unit to act as a single point of contact for industry to ensure there is an effective, streamlined approach for the regulations that fall within our responsibility.”

Steve Walker, the Health and Safety Executive’s Head of Offshore Oil and Gas Safety, said:

“HSE will be working closely alongside our partners on fracking, building on expertise gained from regulating other forms of oil and gas extraction.

“Over the past 16 years HSE has worked very closely with the Environment Agency on regulating a range of high hazard industries in England and Wales and we are developing our joint approach to the regulation of unconventional gas.

“We will play our full part in taking forward any proposals for the regulatory regime, working with the new Office for Unconventional Gas and Oil.”

Source E: Extract from report published by Royal Society and Royal Academy of Engineering.

Shale gas extraction in the UK: a review of hydraulic fracturing

June 2012

Shale gas extraction in the UK: a review of hydraulic fracturing
Issued: June 2012 DES2597

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royalsociety.org/policy/projects/shale-gas-extraction and **raeng.org.uk/shale**

M/Jun14/SCIS4/PM

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Full contents list of the original report.

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Summary

The health, safety and environmental risks associated with hydraulic fracturing (often termed 'fracking') as a means to extract shale gas can be managed effectively in the UK as long as operational best practices are implemented and enforced through regulation. Hydraulic fracturing is an established technology that has been used in the oil and gas industries for many decades. The UK has 60 years' experience of regulating onshore and offshore oil and gas industries.

Concerns have been raised about the risk of fractures propagating from shale formations to reach overlying aquifers. The available evidence indicates that this risk is very low provided that shale gas extraction takes place at depths of many hundreds of metres or several kilometres. Geological mechanisms constrain the distances that fractures may propagate vertically. Even if communication with overlying aquifers were possible, suitable pressure conditions would still be necessary for contaminants to flow through fractures. More likely causes of possible environmental contamination include faulty wells, and leaks and spills associated with surface operations. Neither cause is unique to shale gas. Both are common to all oil and gas wells and extractive activities.

Ensuring well integrity must remain the highest priority to prevent contamination. The probability of well failure is low for a single well if it is designed, constructed and abandoned according to best practice. The UK's well examination scheme was set up so that the design of offshore wells could be reviewed by independent, specialist experts. This scheme must be made fit for purpose for onshore activities. Effects of unforeseen leaks or spills can be mitigated by proper site construction and impermeable lining. Disclosure of the constituents of fracturing fluid is already mandatory in the UK. Ensuring, where possible, that chemical additives are non-hazardous would help to mitigate the impact of any leak or spill.

Concerns have also been raised about seismicity induced by hydraulic fracturing. Natural seismicity in the UK is low by world standards. On average, the UK experiences seismicity of magnitude 5 M_L (felt by everyone nearby) every twenty years, and of magnitude 4 M_L (felt by many people) every three to four years. The UK has lived with seismicity induced by coal mining activities or the settlement of abandoned mines for a long time. British Geological Survey records indicate that coal mining-related seismicity is generally of smaller magnitude than natural seismicity and no larger than 4 M_L. Seismicity induced by hydraulic fracturing is likely to be of even smaller magnitude. There is an emerging consensus that the magnitude of seismicity induced by hydraulic fracturing would be no greater than 3 M_L (felt by few people and resulting in negligible, if any, surface impacts). Recent seismicity induced by hydraulic fracturing in the UK was of magnitude 2.3 M_L and 1.5 M_L (unlikely to be felt by anyone). The risk of seismicity induced by hydraulic fracturing can be reduced by traffic light monitoring systems that use real-time seismic monitoring so that operators can respond promptly.

Monitoring should be carried out before, during and after shale gas operations to inform risk assessments. Methane and other contaminants in groundwater should be monitored, as well as potential leakages of methane and other gases into the atmosphere. The geology of sites should be characterised and faults identified. Monitoring data should be submitted to the UK's regulators to manage potential hazards, inform local planning processes and address wider concerns. Monitoring of any potential leaks of methane would provide data to assess the carbon footprint of shale gas extraction.

The UK's goal based approach to regulation is to be commended, requiring operators to identify and assess risks in a way that fosters innovation and continuous improvement in risk management. The UK's health and safety regulators and environmental regulators should work together to develop guidelines specific to shale gas extraction to help operators carry out goal based risk assessments according to the principle of reducing risks to As Low As Reasonably Practicable (ALARP). Risk assessments should be submitted to the regulators for scrutiny and then enforced through monitoring activities and inspections. It is mandatory for operators to report well failures, as well as other accidents and incidents to the UK's regulators. Mechanisms should be put in place so that reports can also be shared between operators to improve risk assessments and promote best practices across the industry.

An Environmental Risk Assessment (ERA) should be mandatory for all shale gas operations. Risks should be assessed across the entire lifecycle of shale gas extraction, including risks associated with the disposal of wastes and abandonment of wells. Seismic risks should also feature as part of the ERA.

Water requirements can be managed through integrated operational practices, such as recycling and reusing wastewaters where possible. Options for disposing of wastes should be planned from the outset. Should any onshore disposal wells be necessary in the UK, their construction, regulation and siting would need further consideration.

Wastewaters may contain Naturally Occurring Radioactive Material (NORM) that are present in shales at levels significantly lower than safe limits of exposure. These wastewaters are in need of careful management should NORM become more concentrated during waste treatment. NORM management is not unique to shale gas extraction. NORM is present in waste fluids from the conventional oil and gas industries, as well as in mining industries, such as coal and potash. Much work has been carried out globally on monitoring levels of radioactivity and handling NORMs in these industries.

Shale gas extraction in the UK is presently at a very small scale, involving only exploratory activities. Uncertainties can be addressed through robust monitoring systems and research activities identified in this report. There is greater uncertainty about the scale of production activities should a future shale gas industry develop nationwide. Attention must be paid to the way in which risks scale up. Co-ordination of the numerous bodies with regulatory responsibilities for shale gas extraction must be maintained. Regulatory capacity may need to be increased.

Decisions are soon to be made about shale gas extraction continuing in the UK. The next round of issuing Petroleum Exploration and Development Licences is also pending. This report has not attempted to determine whether shale gas extraction should go ahead. This remains the responsibility of the Government. This report has analysed the technical aspects of the environmental, health and safety risks associated with shale gas extraction to inform decision making. Neither risks associated with the subsequent use of shale gas nor climate risks have been analysed. Decision making would benefit from research into the climate risks associated with both the extraction and use of shale gas. Further benefit would also be derived from research into the public acceptability of all these risks in the context of the UK's energy, climate and economic policies.

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Recommendations

Recommendation 1
To detect groundwater contamination:

- The UK's environmental regulators should work with the British Geological Survey (BGS) to carry out comprehensive national baseline surveys of methane and other contaminants in groundwater.
- Operators should carry out site-specific monitoring of methane and other contaminants in groundwater before, during and after shale gas operations.
- Arrangements for monitoring abandoned wells need to be developed. Funding of this monitoring and any remediation work needs further consideration.
- The data collected by operators should be submitted to the appropriate regulator.

Recommendation 2
To ensure well integrity:

- Guidelines should be clarified to ensure the independence of the well examiner from the operator.
- Well designs should be reviewed by the well examiner from both a health and safety perspective and an environmental perspective.
- The well examiner should carry out onsite inspections as appropriate to ensure that wells are constructed according to the agreed design.
- Operators should ensure that well integrity tests are carried out as appropriate, such as pressure tests and cement bond logs.
- The results of well tests and the reports of well examinations should be submitted to the Department of Energy and Climate Change (DECC).

Recommendation 3
To mitigate induced seismicity:

- BGS or other appropriate bodies should carry out national surveys to characterise stresses and identify faults in UK shales. Operators should carry out site-specific surveys to characterise and identify local stresses and faults.
- Seismicity should be monitored before, during and after hydraulic fracturing.
- Traffic light monitoring systems should be implemented and data fed back to well injection operations so that action can be taken to mitigate any induced seismicity.
- DECC should consider how induced seismicity is to be regulated. Operators should share data with DECC and BGS to establish a national database of shale stress and fault properties so that suitable well locations can be identified.

Recommendation 4
To detect potential leakages of gas:

- Operators should monitor potential leakages of methane or other emissions to the atmosphere before, during and after shale gas operations.
- The data collected by operators should be submitted to the appropriate regulator. These data could inform wider assessments, such as the carbon footprint of shale gas extraction.

Recommendation 5
Water should be managed in an integrated way:

- Techniques and operational practices should be implemented to minimise water use and avoid abstracting water from supplies that may be under stress.
- Wastewater should be recycled and reused where possible.
- Options for treating and disposing of wastes should be planned from the outset. The construction, regulation and siting of any future onshore disposal wells need further investigation.

Recommendation 6
To manage environmental risks:

- An Environmental Risk Assessment (ERA) should be mandatory for all shale gas operations, involving the participation of local communities at the earliest possible opportunity.

- The ERA should assess risks across the entire lifecycle of shale gas extraction, including the disposal of wastes and well abandonment. Seismic risks should also feature as part of the ERA.

Recommendation 7
Best practice for risk management should be implemented:

- Operators should carry out goal based risk assessments according to the principle of reducing risks to As Low As Reasonably Practicable (ALARP). The UK's health and safety regulators and environmental regulators should work together to develop guidelines specific to shale gas extraction to help operators do so.

- Operators should ensure mechanisms are put in place to audit their risk management processes.

- Risk assessments should be submitted to the regulators for scrutiny and then enforced through monitoring activities and inspections.

- Mechanisms should be put in place to allow the reporting of well failures, as well as other accidents and incidents, between operators. The information collected should then be shared to improve risk assessments and promote best practices across the industry.

Recommendation 8
The UK's regulators should determine their requirements to regulate a shale gas industry should it develop nationwide in the future. Skills gaps and relevant training should be identified. Additional resources may be necessary.

Recommendation 9
Co-ordination of the numerous bodies with regulatory responsibilities for shale gas extraction should be maintained. A single body should take the lead. Consideration should be given to:

- Clarity on roles and responsibilities.

- Mechanisms to support integrated ways of working.

- More formal mechanisms to share information.

- Joined-up engagement of local communities.

- Mechanisms to learn from operational and regulatory best practice internationally.

Recommendation 10
The Research Councils, especially the Natural Environment Research Council, the Engineering and Physical Sciences Research Council and the Economic and Social Research Council, should consider including shale gas extraction in their research programmes, and possibly a cross-Research Council programme. Priorities should include research into the public acceptability of the extraction and use of shale gas in the context of UK policies on climate change, energy and the wider economy.

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Terms of reference

The UK Government's Chief Scientific Adviser, Sir John Beddington FRS, asked the Royal Society and the Royal Academy of Engineering to carry out an independent review of the scientific and engineering evidence relating to the technical aspects of the risks associated with hydraulic fracturing to inform government policymaking about shale gas extraction in the UK.

The terms of reference of this review were:

- What are the major risks associated with hydraulic fracturing as a means to extract shale gas in the UK, including geological risks, such as seismicity, and environmental risks, such as groundwater contamination?

- Can these risks be effectively managed? If so, how?

This report has analysed environmental and health and safety risks. Climate risks have not been analysed. The risks addressed in this report are restricted to those associated with the onshore extraction of shale gas. The subsequent use of shale gas has not been addressed.

Methodology
A Working Group was set up to oversee this project (see Appendix 1). The Working Group met on six occasions when it was briefed by other experts. Consultations with other experts and stakeholders were held between meetings. Submissions were received from a number of individuals and learned societies (see Appendix 2). This report has been reviewed by an expert Review Panel (see Appendix 3) and approved by the Engineering Policy Committee of the Royal Academy of Engineering and the Council of the Royal Society.

The Royal Academy of Engineering and The Royal Society are grateful to the Government Office for Science for its financial support for this review.

CHAPTER 1

1.2 Stages of shale gas extraction

Shale gas extraction consists of three stages:

- **Exploration.** A small number of vertical wells (perhaps only two or three) are drilled and fractured to determine if shale gas is present and can be extracted. This exploration stage may include an appraisal phase where more wells (perhaps 10 to 15) are drilled and fractured to characterise the shale; examine how fractures will tend to propagate; and establish if the shale could produce gas economically. Further wells may be drilled (perhaps reaching a total of 30) to ascertain the long-term economic viability of the shale.

- **Production.** The production stage involves the commercial production of shale gas. Shales with commercial reserves of gas will typically be greater than a hundred metres thick and will persist laterally over hundreds of square kilometres. These shales will normally have shallow dips, meaning they are almost horizontal. Vertical drilling would tend to pass straight through them and access only a small volume of the shale. Horizontal wells are likely to be drilled and fractured. Once a shale formation is reached by vertical drilling, the drill bit can be deviated to run horizontally or at any angle.

- **Abandonment.** Like any other well, a shale gas well is abandoned once it reaches the end of its producing life when extraction is no longer economic. Sections of the well are filled with cement to prevent gas flowing into water-bearing zones or up to the surface. A cap is welded into place and then buried.

1.3 The global policy context

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1.3.2 Global climate change and energy security

Shale gas is championed by some commentators as a 'transition fuel' in the move towards a low carbon economy, helping to displace higher-emitting fuels, such as coal. Others argue that shale gas could supplement rather than displace coal use, further locking in countries to a fossil fuel economy. The development of shale gas could also reduce and/or delay the incentive to invest in zero- and low-carbon technologies and renewable energy. There are concerns that even small leakages of methane during shale gas extraction may offset the effects of lower carbon dioxide emissions. The global warming potential of a molecule of methane is greater than that of carbon dioxide, but its lifetime in the atmosphere is shorter. On a 20-year timescale, the global warming potential of methane is 72 times greater than that of carbon dioxide. On a century timescale, it is 25 times greater.

1.4 Environmental concerns in the USA

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1.4.1 Improper operational practices

There has been widespread concern in the USA about the environmental impact of hydraulic fracturing. One cause for concern has been improper operational practices. A US Environmental Protection Agency (EPA) study reported that hydraulic fracturing had contaminated groundwater and drinking water supplies in Pavillion, Wyoming. The well casing was poorly constructed, and the shale formations that were fractured were as shallow as 372m. Many claims of contaminated water wells due to shale gas extraction have been made. None has shown evidence of chemicals found in hydraulic fracturing fluids. Water wells in areas of shale gas extraction have historically shown high levels of naturally occurring methane before operations began. Methane detected in water wells with the onset of drilling may also be mobilised by vibrations and pressure pulses associated with the drilling. In 2011, the EPA was directed by Congress to undertake a study to better understand the potential impacts of hydraulic fracturing on drinking water resources. This EPA study is examining impacts from the acquisition of water and its mixing with chemicals to create fracture fluid, through to the management of flowback and produced water, including disposal. A first report is expected at the end of 2012. The final results are due in 2014. In 2011, the Secretary of Energy Advisory Board Natural Gas Subcommittee submitted its recommendations to improve the safety and environmental performance of shale gas extraction.

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1.5 Environmental concerns in Europe

Shale gas extraction in Europe is at the exploration stage. It is many years away from US levels of commercial production, especially in the light of differences in geology, public acceptability, population density, tax breaks and environmental regulation. In 2011, European Union (EU) Heads of State concluded that Europe's potential to extract and use unconventional fossil fuel resources, including shale gas, should be assessed. In 2012, the European Commission (EC) judged that its existing legal framework was adequate to address shale gas extraction. Shale gas could reduce some European countries' dependence on natural gas imports.

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1.7 Concerns about seismicity

Concerns in the UK have focused on seismicity induced by hydraulic fracturing. 'Seismicity' or 'seismic events' refer to sudden phenomena that release energy in the form of vibrations that travel through the Earth as sound (seismic) waves. Energy may be released when rocks break and slide past each other on surfaces or cracks ('faults'). Energy may also be released when rocks break in tension, opening up cracks or fractures. The passage and reflection of seismic waves can be monitored by seismometers at seismic stations. Geophones are used along regular lines ('seismic lines') or grids to obtain two- or three-dimensional profiles of the Earth's subsurface structure ('seismic reflection surveys'). Seismicity is measured according to the amount of energy released (magnitude) or the effect that energy release has at the Earth's surface (intensity).

On 1st April 2011, the Blackpool area in north England experienced seismicity of magnitude 2.3 M_L shortly after Cuadrilla Resources ('Cuadrilla', hereafter) hydraulically fractured a well at its Preese Hall site. Seismicity of magnitude 1.5 M_L occurred on 27th May 2011 following renewed fracturing of the same well. Hydraulic fracturing was suspended. Cuadrilla commissioned a set of reports to investigate the cause of seismicity. The Department of Energy and Climate Change (DECC) also commissioned an independent report that was published for public comment.

CHAPTER 8

Research on shale gas

8.1 Uncertainties affecting small scale exploratory activities

Uncertainties affecting the small scale exploratory activities in the UK can be addressed through effective monitoring systems and research programmes before shale gas extraction commences on any significant scale. Research priorities include:

- technologies to reduce water requirements for hydraulic fracturing;
- improving understanding of UK shales and the composition of wastewaters;
- technologies to treat wastewaters;
- methods to determine sources of methane;
- monitoring the long term behaviour of wells, including after abandonment;
- improving understanding of mechanical and flow properties of shale;
- improving the effectiveness of traffic light monitoring systems and statistical models to forecast induced seismicity.

8.2 Uncertainties affecting large scale production activities

More significant uncertainties concern the scale of production activities should a shale gas industry develop nationwide. The potential scale will be dictated by the UK's potential shale gas resources, as well as government policy making. This report has addressed environmental, health and safety risks associated with shale gas extraction. Policymaking would benefit from research into the climate risks associated with the extraction and subsequent use of shale gas. This report has focused on the technical aspects of the risks associated with hydraulic fracturing. Policy making would also benefit from research into the public acceptability of shale gas extraction and use in the context of wider UK policies, including:

- climate change policy, especially the impact of shale gas extraction on the UK meeting its emissions targets;
- energy policy, especially the impact of shale gas development on investment in renewable energy;
- economic policy, including socioeconomic benefits from employment to tax revenue and from shale gas use.

8.2.1 The UK's proven reserves of shale gas

Various estimates of the extent of certain areas in the UK with shale gas resources have been provided. It will be some years before shale gas production data and the impact of regulatory and economic conditions allow a rigorous estimate of the UK's proven reserves of shale gas.

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8.2.2 The carbon footprint of shale gas extraction

There are few reliable estimates of the carbon footprint of shale gas extraction and use in the peer reviewed literature. One US study from Cornell University concluded that the carbon footprint of shale gas extraction is significantly larger than from conventional gas extraction owing to potential leakages of methane. The same study recognised the large uncertainty in quantifying these methane leakages, highlighting that further research is needed. Data collected from methane monitoring submitted to the UK's regulators could be used to inform assessments to reduce this uncertainty.

8.2.3 The public acceptability of shale gas extraction

The Economic and Social Research Council has funded extensive research to better understand the public views of low carbon fuels, such as nuclear power. Government decision making would benefit from similar research into the public acceptability of shale gas extraction within the context of wider government policies. Opportunities should be created to allow expert understanding about risks to be challenged and 'blind spots' to be explored.

Different perspectives on hydraulic fracturing do not neatly divide into views held by experts and those held by 'the public'. 'The public at large', civil society organisations, those who adopt more sceptical perspectives on technological developments, as well as protest groups should all be involved in this research. This will help ensure the government addresses issues of actual, rather than assumed, public concern. This research should also investigate what makes a regulator trustworthy. Concerns tend to focus less on a particular technology *per se* and more on how the technology is governed in real world circumstances. This is problematic in the light of a lack of trust in the government to act in the public interest and ensure adequate regulatory oversight.

8.3 Funding research on shale gas

The majority of shale gas research is carried out by the industry where most expertise is located. Publicly funded research may be necessary to ensure confidence that decision making is informed by independent, evidence-based research. There is currently no cross-Research Council or Technology Strategy Board (TSB) programme specifically addressing shale gas extraction. Such a programme could provide an integrated and interdisciplinary assessment of the risks and opportunities associated

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with shale gas extraction and use in the UK. It could help to focus efforts and ensure that national needs are met while drawing on research efforts elsewhere, especially in the USA and in Europe.

A cross-Research Council programme could be based on existing precedents. Involving 15 UK higher education partners and institutes, the UK Carbon Capture and Storage Consortium was set up in 2005 to rapidly expand a UK research capacity for carbon capture and storage, involving engineers, natural and social scientists. Launched in 2008 as a 10-year partnership, the Living With Environmental Change (LWEC) partnership includes research councils, government departments, devolved administrations and government agencies.

LWEC fosters collaboration between projects that can deliver benefits to multiple partners. Member organisations with their own budgets can pay an annual subscription, contribute staff resources to run a small directorate or contribute to common needs.

The Geological Society of London has established a Geosciences Skills Forum (GSF) in partnership with the Petroleum Exploration Society of Great Britain, British Geological Survey and other partners. GSF could broker a dialogue between the Research Councils, TSB, DECC, Department for Communities and Local Government, Department for Environment, Food and Rural Affairs and Environment Agency and the wider geosciences community about research priorities and capacity needs.

References

The report contained 88 references which have been removed.

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