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Shale gas and hydraulic fracture – an overview of existing research

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This paper examines national and supra-national literature on shale gas development with a focus on environmental concerns; resource assessments; and the interaction between shale gas development and growth in renewable generation

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Key Points

This paper provides a review of existing literature, sourced from national and supranational bodies, and examines the potential impacts of shale gas development, with a specific focus on environmental concerns, resource availability and the interaction with renewable energy development.

A review of the literature has identified a number of risks. These risks are largely environmental and concern the interaction with water supplies, greenhouse gas emissions, seismic activity, and land consumption. Quantifying the level of risk is, however, problematic due to a number of unanswered questions and apparent knowledge gaps. This includes:

- A definitive answer to the question 'can hydraulic fracturing impact drinking water resources?' has not been established.
- A full understanding of the level of water consumed is dependent on a specific location. The impact of increased consumption is also likely to be location dependent.
- The question of what proportion of waste water returns to the surface remains unresolved. Policy makers and industry will also have to address how this waste water is treated.
- Concerns exist around greenhouse gas emissions. The evidence suggests a robust lifecycle analysis of emissions levels remains outstanding.
- Policy makers are recommended, by the IEA amongst others, to ensure robust regulations on well design, construction, cementing and testing.
- A better understanding of local geology should help to improve methods of fracture control and identify areas where the potential for induced seismic activity exists.

It should be noted that a large proportion of these risks are likely to fall within the remit of the Department of the Environment.

Key aspects arising from the remainder of the paper concern potential resource and the impact on renewable development, namely:

- The European Parliament's report does not appear optimistic with regard to shale gas' impact on the European energy mix. They do not, however, rule out positive impacts at regional level. The House of Common's notes that although shale gas might contribute to the UK's energy mix and to security of supply it is unlikely to be a game changer.
- A number of gaps between the US and elsewhere have been identified – e.g. skills and infrastructure – which may hamper the development of available resources. Consideration might be given as to how these gaps may be addressed.

- Debate exists over the depletion rate of shale gas wells. A robust answer to this is desirable as it is likely to have significant implications on the resource's future role within the energy mix.
- Although, as argued by the UK Government, fossil fuels will continue to play a role in the energy mix, consideration should be given to the signals shale gas development sends to renewable energy markets and the impacts the development of the former might have on the latter.

Further consideration may be given to how developers and government interact with the public with the literature arguing that transparency and early public involvement are desirable.

A number of on-going pieces of work have been identified which will provide greater clarity on some of the significant issues – including emissions, water contamination, UK geology, and the health impacts of shale gas development. As such a final determination on these factors may be premature.

Scope for further work has also been identified, this includes:

- A full-life cycle analysis of shale gas development to determine its greenhouse gas foot print compared to other energy resources;
- Enhancing the understanding of UK shales, including resource levels, and stresses and faults;
- Monitoring of behaviour of wells after abandonment;
- Further work to define the volume and content of produced water (specific to location);
- The interaction between shale gas development and climate change policy, including renewables;
- Further research and development into shale gas to improve efficiency and enhance environmental protection; and,
- An overview and assessment of Northern Ireland regulations.

Executive Summary

The following paper examines national and supra-national literature on shale gas development with a focus on environmental concerns; resource assessments; and the interaction between shale gas development and growth in renewable generation.

To achieve this, reports from the following institutions have been surveyed:

- The US Department of Energy;
- The US Environmental Protection Agency;
- The International Energy Agency;
- The European Parliament's Directorate General for Internal Polices – Department of Economic and Science Policy;
- The House of Commons Energy and Climate Change Committee (and the UK government's response to their work);
- The Royal Society and Royal Academy of Engineers (commissioned by the UK government, herein the Joint Academies Study); and
- The University of Aberdeen (commissioned by the government of the Republic of Ireland).

Each of the above papers draws heavily on experiences in the US as until recently this was the predominate location of shale gas development. Development in the US is viewed as successful at a government level there. In 2001 shale gas accounted for 2% of the country's natural gas production, by 2011 this had risen to 30%. It estimated that shale gas has led to the creation of 200,000 direct, indirect and induced jobs, with tens of thousands predicted for the future.

Environmental concerns surround:

- Water contamination, consumption and waste water disposal;
- Greenhouse gas emissions and air pollution;
- Well integrity;
- The impacts of drilling, including, fracture propagation and seismic activity; and
- The impact on landscape and land usage.

Water contamination: the contamination of water in general and of drinking water in particular is a major concern. Individual incidents of water contamination from fracturing fluid (Pavillion) and from methane (northern Pennsylvania) have been recorded. Two potential sources have been identified – from chemical additives in fracturing fluid and from chemicals (e.g. methane) already existing in the formation. Debate on this issue is on-going. Further illumination on the issue is likely to be provided by the EPA study on *Potential Impact of Hydraulic Fracturing on Drinking water resources*, due for publication in draft form in 2012. The potential for chemical-free fracking fluid may require further research and development.

Water consumption: the evidenced examined agrees that hydraulic fracturing requires large quantities of water. There is, however, no definitive figure on what volume is required, due to variations between specific wells and shales. Moreover, there is debate over how water use in hydraulic fracturing compares to conventional gas extraction. A key consideration is how increased water use might affect local water supplies. Over a decade it is estimated that the typical volume used is estimated to be approximately 19,000m^3. The Joint Academies but this into context by comparing it to the amount needed to water a golf course, power a 1000mw coal fired power plant for 12 hours, or the amount lost in leaks by United Utilities' in North West England every hour. Some possible methods of minimising the impact of increased water consumption have been outlined in the literature, namely recycling waste waters, using alternatives to fresh water and developing waterless fracturing fluid.

Waste water: there is debate within the literature as to what proportion of fracturing fluid returns to the surface as waste water. Estimates vary from between 9% and 35% and from between 25% and 75%. How this water is treated is potentially a significant issue as it may contain salt, natural organic and inorganic compounds, chemical additives used in fracturing fluid and NORM (Naturally Occurring Radioactive Material). Furthermore, the Joint Academies argue that little is known about UK shales to explain the level of water that might be returned and what that water might contain. The Joint Academies recommends that waste water managements plans are developed at an early stage, whilst the House of Commons Committee recommends that industry works together to optimise waste water treatment facilities.

Greenhouse gas emissions: considerable debate exists around the greenhouse gas footprint of shale gas. What is evident from the literature surveyed is that a 'cradle-to-grave' analysis of emissions levels, which considers factors such as the burning of the final product, emissions during extractions and emissions during transportation, is yet to be completed. Such a study would likely allow for better understanding of the potential impact of shale gas development, however, cost has been identified as a major constraint. The evidence assessed highlights that emissions mitigation is likely to be a key consideration for the industry and policy makers. According to the Joint Academies report thought should be given to carrying out emissions monitoring before, during and after drilling operations. Further consideration may also be given to following the US's lead in making green completion techniques mandatory.

Well integrity: ensuring well was integrity highlighted in one study as the *'highest priority to prevent contamination'.* There is agreement within the literature that consideration be given to how wells are monitored and what minimum standards should be imposed.

Fracture propagation: uncontrolled fracture propagation may increase the risk of water contamination and seismic activity. The literature suggests that it is in the economic interests of developers to control fracture growth. Mitigation and monitoring are key to reducing unwanted or uncontrolled propagation.

Seismic activity: there is agreement in the literature that hydraulic fracturing can lead to seismic activity. It can be caused by the propagation of fractures, or through fracturing a pre-stressed fault. The evidence suggests that more can be done to *'characterise stresses and identify faults'* throughout the UK, and a process of national surveys has been recommended.

Land-consumption: shale gas production is likely to lead to consumption of land for well development, water storage and transport. This has the potential to lead to ecological, visual and other disruption.

Resources: despite the transformation of the US gas industry prompted by the development of shale gas there, the European Parliament is cautious over how much impact the resources available in Europe will have on European energy markets. UK resources are likely to be considerable and could increase security of supply but the impact of shale gas is unlikely to be a game changer. This finding applies to both the level of resource and impact (or lack thereof) this resource has on energy prices. A number of factors influencing successful resource exploitation in the US and potentially absent in other regions were identified. These included production experience; gas prices and their relation to investment outlays; regulatory frameworks; population densities; land owner rights; gas and other infrastructure; and availability of exploration technology.

Renewable development: The literature has raised concerns over whether shale gas exploration could displace renewable development. Countering this is the UK government's assertion that fossil fuels will continue to play an important part in the energy mix as renewable energy comes on-stream, enabling the integration of intermittent resources.

Other considerations: the importance of transparency and data sharing is highlighted throughout the literature. Transparency is viewed as key to reducing public concern. Extending transparency to disclosing the chemicals in fracturing fluid is also recommended by the Subcommittee

Furthermore early involvement of the public in the decision making process was viewed by the Joint Academies as a way in which 'public frustration' could be reduced.

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1 Introduction

The use of unconventional gas in general and shale gas in particular has caused significant debate amongst policy makers, academics and interest groups on a global scale. In 2012, the International Energy Agency stated, optimistically that:

> *Natural gas is poised to enter a golden age, but this future hinges critically on the successful development of the world's vast unconventional gas resources. North American experience shows unconventional gas - notably shale gas - can be exploited economically. Many countries are lining up to emulate this success.*[1]

Within the United States the exploitation of shale gas is viewed as *'vital to meeting future energy demand and to enabling the nation to transition to greater reliance on renewable energy sources'.*[2]

In 2011, President Obama stated that *'recent innovations have given us the opportunity to tap large reserves* [of shale gas] – *perhaps a century's worth'.*[3]

The US has had significant experience with shale gas extraction. In 2001 shale gas accounted for 2% of the country's natural gas production, by 2011 this had risen to 30%. In 2008 shale gas had its *'big bang'* moment, and since that year production increased four-fold. Continued expansion in the market is expected. Predictions are that shale gas will account for 46% of domestic production by 2035.[4]

It is estimated that shale gas has led to the creation of 200,000 direct, indirect and induced jobs, with tens of thousands predicted for the future. The development of the [1]resource has led to the US becoming essentially self-sufficient in natural gas. Gas prices have also fallen considerably (two-fold) since 2008.[5]

Despite the positivity the surrounds the shale gas industry in the US, some governments, both internationally (France) and locally (New York State), *'are hesitant, or even actively opposed'* to develop the resource. This reluctance stems from a reaction to *'public concerns that production might involve unacceptable environmental and social damage'.*[6] Such concerns focus on the product – shale gas – and the method of extracting it from the ground – hydraulic fracture.

[1] The International Energy *Golden Rules for a Golden Age of Gas* (Press release) (May 2012) http://www.worldenergyoutlook.org/goldenrules/

[2] The US Department of Energy *Modern Shale Gas development in the US - a Primer* (2009) http://www.netl.doe.gov/technologies/oil-gas/publications/epreports/shale_gas_primer_2009.pdf

[3] The US Department of Energy – Shale Gas Subcommittee of the Secretary of Energy Board Advisory Board Shale Gas Production *90 day report* (August 2011) http://www.shalegas.energy.gov/resources/081111_90_day_report.pdf

[4] *Ibid*

[5] *Ibid*

[6] The International Energy *Golden Rules for a Golden Age of Gas* (Press release) (May 2012) http://www.worldenergyoutlook.org/goldenrules/

In this paper, existing research is used to examine these concerns. Areas of convergence are highlighted, along with gaps in the research base and future publications. The paper adopts a thematic approach, focusing on the following areas:

- Environmental concerns;
- Resource assessments and the potential contribution of shale gas to the energy mix; and
- The interaction between shale gas development and growth in renewable generation.

These three factors do not represent an exhaustive list of possible issues potentially arising from shale gas development. They, however, reflect the focus of the papers considered.

The paper makes use of research conducted by national and supranational governments and government bodies. In particular, the perspectives of (or studies commissioned by) the following organisations have been considered:

- The US Department of Energy;
- The US Environmental Protection Agency;
- The International Energy Agency;
- The European Parliament's Directorate General for Internal Polices – Department of Economic and Science Policy;
- The House of Commons Energy and Climate Change Committee (and the UK government's response to their work);
- The Royal Society and Royal Academy of Engineers (commissioned by the UK government, herein the Joint Academies Study); and
- The University of Aberdeen (commissioned by the government of the Republic of Ireland).

The paper does not focus extensively on the academic debate surrounding shale gas and its extraction. There are a number of reasons for this. Firstly, the technical nature of this work means that it is beyond the scope of this paper. Secondly, the debate is on-going and unresolved. Finally, the research taking place with academia is considered and has informed much of the governmental research that forms the basis of this paper.

Each of the studies examined draws heavily from experiences in the US. This is largely done for practical reasons as *'until recently, unconventional natural gas production was almost exclusively a US phenomenon'*.[7]

[7] The International Energy *Golden Rules for a Golden Age of Gas* (May 2012) http://www.worldenergyoutlook.org/media/weowebsite/2012/goldenrules/WEO2012_GoldenRulesReport.pdf

2 Environmental Concerns

Concern exists around the environmental impact of shale gas and of hydraulic fracture. The potential impacts most discussed in the studies examined were:

- Water contamination, consumption and waste water disposal;
- Greenhouse gas emissions and air pollution;
- Well integrity;
- The impacts of drilling, including, fracture propagation and seismic activity; and
- The impact on landscape and land usage.

Each of these areas is considered in this section.

2.1 Water contamination, consumption and waste water disposal

The interaction between hydraulic fracturing and water systems has been amongst the most prominent area of debate. This is due, in part, to the success of the 2010 documentary *Gasland,* which largely focussed on the issue of water contamination.

The studies examined for this paper devote a considerable amount of space to analysing the potential impacts hydraulic fracturing might have on water systems. Three areas in particular have been discussed: potential water contamination due to the hydraulic fracture; water consumption due to hydraulic fracture; and the disposal of waste water resulting from hydraulic fracture.

2.1a Water contamination

The European Parliament Directorate General for Internal Polices – Department of Economic and Science Policy drew on US experience to identify a number of possible ways that water may become contaminated by the hydraulic fracturing process:

- Spills of drilling mud, flow back and brine from storage tanks etc. leading to water contamination and salinization;
- Leaks or accidents from surface activities – for example leakage from waste water pipes;
- Leaks from the inadequate cementing of wells; and
- Leaks through natural or artificial cracks or pathways in geological structures.[8]

In 2011, the US Environmental Protection Agency (US EPA) published draft findings of a study into a specific case of suspected water contamination, in Pavillion, Wyoming. This study arose from complaints by local residents (in 2008) regarding *'objectionable taste and odour problems'* from water taken from domestic wells. During the study the

[8] European Parliament Directorate General for Internal Polices - Department of Economic and Science Policy *Impacts of shale gas and shale oil extraction on the environment and human health* (June 2011) http://www.europarl.europa.eu/document/activities/cont/201107/20110715ATT24183/20110715ATT24183EN.pdf

EPA carried out a series of *'sampling events'* between March 2009 and April 2011. There were four sampling phases in total which saw water samples collected from public and private drinking wells, as well as surface water and from two monitoring wells installed by the agency. These samples were analysed and their content was established.[9]

The analysis of the monitoring wells detected:

- Synthetic chemicals (such as glycols and alcohols) associated with fracturing fluids;
- Benzene concentrations above those outlined in the US Safe Drinking Water Act; and,
- High methane levels.[10]

The US EPA concluded:

> *Given the area's complex geology and the proximity of drinking water wells to ground water contamination, EPA is concerned about the movement of contaminants within the aquifer and the safety of drinking water wells over time.*[11]

With regard to the analysis of samples taken from public and private drinking wells, the USEPA identified chemicals (including methane and *'other'* petroleum hydrocarbons) *'consistent with migration from areas of gas production'*. These chemicals were below health and safety standards and it was recommended that well owners take precautionary measures, including sourcing alternative sources of water for drinking and cooking, and ensuring ventilation when showering.[12]

The Pavillion study has only been published in draft form. This is for two reasons – to enable peer review and to facilitate further sampling. The peer review period was recently extended until October 2012. A final draft of the paper will be produced following this although no date has yet been set.[13] The study will address two questions:

- Can hydraulic fracturing impact drinking water resources?
- If so, what conditions are associated with these potential impacts?

The US EPA has also committed to a broader investigation into the *Potential Impact of Hydraulic Fracturing on Drinking Water Resources.* This study, which is on-going, is

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[9] US EPA *Pavillion, Wyoming Ground Water Investigation – Draft Report* (December 2011) http://www.epa.gov/region8/superfund/wy/pavillion/EPA_ReportOnPavillion_Dec-8-2011.pdf

[10] *Ibid*

[11] *Ibid*

[12] *Ibid*

[13] US EPA *Groundwater investigation – What's new?* http://www.epa.gov/region8/superfund/wy/pavillion/index.html (accessed 13 August 2012)

due for publication in draft form in late 2012. The final peer reviewed publication is expected in 2014.[14]

The US Department of Energy's Shale Gas Subcommittee's 90 Day Report on shale gas and hydraulic fracturing (August 2011), noted that:

> *One of the commonly perceived risks from hydraulic fracturing is the possibility of leakage of fracturing fluid through fractures into drinking water. Regulators and geophysical experts agree that the likelihood of properly injected fracturing fluid reaching drinking water through fractures is remote where there is a large depth separation between drinking water sources and the producing zone. In the great majority of regions where shale gas is being produced, such separation exists and there are few, if any, documented examples of such migration.*[15]

What is contained in the fracturing fluid is tailored to meet the *'specific conditions of the target formation'.*[16] The largest components of the fluid are usually water and sand. Figure 1, provides a typical breakdown of fracturing fluid. The specific nature of the chemical additives may vary between fracturing jobs. On the chemicals, the British Geological Society commented:

> *The 0.17% of chemical additives may include scale inhibitors to prevent the build-up of scale on the well; acid to help initiate fractures; biocide to kill bacteria that can produce hydrogen sulphate and lead corrosion; friction reducer to reduce friction between the well and the fluid injected into it; and surfactant to reduce the viscosity of the fracturing fluid.*[17]

At first glance, 0.17% appears to be an insignificant amount. Scale is important however. Estimates from the US suggest that 3m US gallons of water on average are required to fracture a single well (further details in the section that follows).[18] To put the 0.17% figure into perspective, 3m US Gallons is equivalent to 11,356.235 cubic meters (m^3), assuming the two figures hold true (for volume and proportion of chemicals) it would mean that 19.31m^3 The figure becomes more significant if multiple well pads fracturing the same well are considered. The potential for chemical free fracturing fluid is discussed at the end of this section.

[14] US EPA EPA's Study of Hydraulic Fracturing and Its Potential Impact on Drinking Water Resources http://www.epa.gov/hfstudy/ (accessed 13 August 2012)

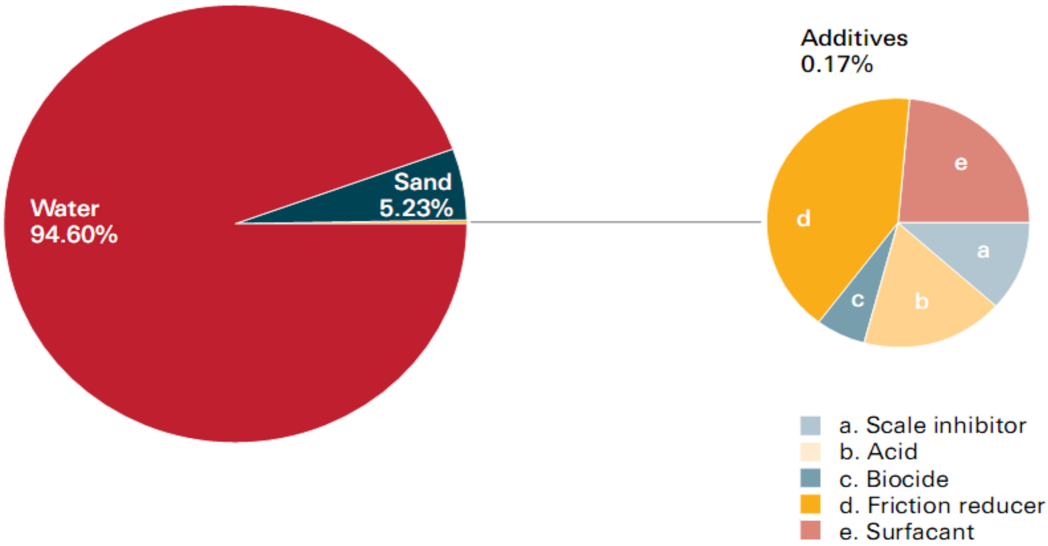
[15] US Department of Energy's *Shale Gas Subcommittee's 90 Day Report on shale gas and hydraulic fracturing (*August 2011) http://www.shalegas.energy.gov/resources/081811_90_day_report_final.pdf

[16] The US Department of Energy *Modern Shale Gas development in the US - a Primer* (2009) http://www.netl.doe.gov/technologies/oil-gas/publications/epreports/shale_gas_primer_2009.pdf

[17] The Royal Society and Royal Academy of Engineers *Shale gas extraction in the UK: a review of hydraulic fracturing* (June 2012) http://royalsociety.org/uploadedFiles/Royal_Society_Content/policy/projects/shale-gas/2012-06-28-Shale-gas.pdf

[18] The US Department of Energy *Modern Shale Gas development in the US - a Primer* (2009) http://www.netl.doe.gov/technologies/oil-gas/publications/epreports/shale_gas_primer_2009.pdf

Figure 1: Typical composition of fracturing fluid by volume



Source: British Geological Society

Returning to the Subcommittee report, it concedes that the incorrect execution of hydraulic fracturing and inadequate well design may lead to water contamination. For example, an *'improperly executed fracturing fluid injection can, of course, lead to surface spills and leakage into surrounding shallow drinking water formations',* and a *'well with poorly cemented casing could potentially leak, regardless of whether the well has been hydraulically fractured'.*[19]

Another potential danger, highlighted in this report as a *'greater concern'*, is methane leakage into water supplies:

> *Methane leakage from producing wells into surrounding drinking water wells, exploratory wells, production wells, abandoned wells, underground mines, and natural migration is a greater source of concern. The presence of methane in wells surrounding a shale gas production site is not ipso facto evidence of methane leakage from the fractured producing well since methane may be present in surrounding shallow methane deposits or the result of past conventional drilling activity.*
>
> *However, a recent, credible, peer-reviewed study documented the higher concentration of methane originating in shale gas deposits… into wells surrounding a producing shale production site in northern Pennsylvania.*[20]

Drawing on industry evidence the report suggests that when methane migration occurs, it can be due to a number of factors (possibly in combination): drilling in a geologically

[19] The US Department of Energy – Shale Gas Subcommittee of the Secretary of Energy Board Advisory Board Shale Gas Production *90 day report* (August 2011) http://www.shalegas.energy.gov/resources/081111_90_day_report.pdf

[20] *Ibid*

unstable area; loss of well integrity due to poor well design; or poor production pressure management. [21]

Based on this analysis the Subcommittee recommended that further studies be carried out to determine the extent of methane migration in other regions. They also suggest that best practice production and monitoring techniques are employed. These include: pressure test on casing and the use of state-of-the-art cement bond logs to promote integrity; micro-seismic surveys; and regulations and inspections to ensure repairs are carried out promptly.[22]

Commenting on the US experience of water contamination from a European perspective, the European Parliament study also takes the view that regulation and monitoring should reduce the risk of contamination:

> *Most of the accidents and ground water intrusions seem to be due to incorrect handling, which could be avoided. Regulations exist in the USA, but monitoring and supervision of operations is rather poor, be it for lack of available budgets of public authorities or for other reasons. Therefore, the basic problem is not inadequate regulation, but their enforcement through adequate supervision. It must be guaranteed that best practice is not only available, but also commonly applied.*[23]

The House of Commons Energy and Climate Change Committee's investigation into shale gas draws a similar conclusion. It states:

> *The successful injection of hydraulic fracturing fluid to release shale gas should result in natural gas production without the contamination of underground sources of drinking water, but this relies upon the integrity of the well and the correct fluid design.*[24]

Concluding:

> *We conclude that hydraulic fracturing itself does not pose a direct risk to water aquifers, provided that the well-casing is intact before this commences. Rather, any risks that do arise are related to the integrity of the well, and are no different to issues encountered when exploring for hydrocarbons in conventional geological formations.*[25]

[21] *Ibid*
[22] *Ibid*
[23] European Parliament Directorate General for Internal Polices - Department of Economic and Science Policy *Impacts of shale gas and shale oil extraction on the environment and human health* (June 2011) http://www.europarl.europa.eu/document/activities/cont/201107/20110715ATT24183/20110715ATT24183EN.pdf
[24] The House of Commons Committee on Energy and Climate Change *Shale Gas Report* (May 2011) http://www.publications.parliament.uk/pa/cm201012/cmselect/cmenergy/795/795.pdf
[25] *Ibid*

On this basis it recommended:

- The Health and Safety Executive test the integrity of wells before licensing of drilling activity;
- The Environment Agency should insist that all companies involved in hydraulic fracture declare the type, concentration and volume of all chemicals they are using; and
- The Environment Agency only permits the use of chemicals where they have the capability to monitor and detect these chemicals in the water supply.[26]

Similar conclusions were again reached by a study conducted by the Royal Society and Royal Academy of Engineers on behalf of the UK government. Commenting on the EPA's Pavillion study (above), it notes the inadequate practice that occurred in that case:

> *The well casing was poorly constructed, and the shale formations that were fractured were as shallow as 372m.*[27]

Adding, more generally, that in the US:

> *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.*[28]

The authors suggest that the broader EPA study will provide a better understanding of the potential impacts of shale gas extraction on drinking water resources.

The study recommended:

- The UK's environmental agency should work with the British Geological Society to carry out comprehensive national baseline surveys of methane and other contaminants in ground water (note this work has begun, with Northern Ireland selected as a priority area);
- 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 should be developed; and
- Data collected by operators should be submitted to the appropriate regulator.[29]

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[26] *Ibid*

[27] The Royal Society and Royal Academy of Engineers *Shale gas extraction in the UK: a review of hydraulic fracturing* (June 2012) http://royalsociety.org/uploadedFiles/Royal_Society_Content/policy/projects/shale-gas/2012-06-28-Shale-gas.pdf

[28] *Ibid*

[29] *Ibid*

With regard to well integrity it recommended:

- 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; and
- The results of well tests and the reports of well examinations should be submitted to the Department of Energy and Climate Change (DECC).[30]

Finally, the University of Aberdeen study, on behalf of the Republic of Ireland EPA, which again drew on experiences of the US, concluded that *'published peer-reviewed data suggest that there is a low and probably manageable risk to ground water from fracking'.* This statement carried an important caveat:

> *However, the total number of published, peer-reviewed scientific studies remains low, and it is therefore prudent to consider and research in detail the full range of possible risks from fracking operations, including their magnitudes and uncertainties, and the potential environmental impacts of these risks in the exploitation of shale gas.*[31]

This study, uniquely, assessed the potential of the use of chemical free fracturing fluid. On this subject it concluded:

> *Scope exists to develop new fracking fluids free from chemical additives, although the sand proppant will probably still be required. If such 'clean' fracking fluids can be shown to be as effective as those with chemical additives, then many of the alleged contamination risks associated with fracking could be reduced or eliminated.*[32]

Adding:

> *Research and development should continue into the viability of removing all toxic additives from fracking fluids. The possibility of additive free fracking fluids (i.e. just water and sand) should be explored, both from a research perspective and industry sponsored testing. How critical are these chemical additives to the fracking process? How risky are they in relation to the*

[30] *Ibid*

[31] The University of Aberdeen *Fracking: Current Knowledge and Potential Environmental Impacts* (May 2012) http://www.epa.ie/downloads/pubs/research/sss/UniAberdeen_FrackingReport.pdf

[32] *Ibid*

> *perceived benefits? New quantitative data are required to address these questions.*[33]

2.1b Water consumption

The US Department of Energy's *Modern Shale Gas Development in the United States: A Primer* report estimates that the *'drilling and hydraulic fracturing of a horizontal shale gas well may typically require 2 to 4 million gallons of water, with about 3 million being the most common'.* They note, however, that the *'the volumes of water needed may vary substantially between wells'* and that *'the volume of water needed for wellbore appears to be decreasing as technologies and methods improve over time'.*[34]

In the more recent US Department of Energy's Shale Gas Subcommittee's 90 Day Report on shale gas and hydraulic fracturing (August 2011), the estimated water use ranges from *'between 1 and 5 million gallons'.* This report also notes that there is a variation in the amount of water used across the US, adding that in *'most regions water used in hydraulic fracturing represents a small fraction of total water consumption'.*[35]

The subcommittee also note that there is *'considerable debate'* concerning the volumes of water used in extracting shale gas compared to the water usage during conventional gas extraction and electricity generation.[36]

The European Parliament report notes that:

> *Large volumes of water are consumed during conventional drilling of the bore hole in order to cool and lubricate the drilling head, but also to remove the drilling mud. About a factor of ten more water is consumed in hydraulic fracturing for the stimulation of the well by injecting over pressurized water for the creation of the cracks.*[37]

It adds too that the amount of water may increase over the lifetime of the well:

> *Furthermore, wells drilled for producing shale gas may have to be fractured several times over the course of their operation time. Each additional fracture operation may require more water than the previous one… In some cases, the wells are refractured up to 10 times.*[38]

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[33] *Ibid*

[34] Us Department of Energy, *Modern Shale Gas Development in the United States: A Primer* (April 2009) http://www.netl.doe.gov/technologies/oil-gas/publications/epreports/shale_gas_primer_2009.pdf

[35] US Department of Energy's *Shale Gas Subcommittee's 90 Day Report on shale gas and hydraulic fracturing (*August 2011) http://www.shalegas.energy.gov/resources/081811_90_day_report_final.pdf

[36] US Department of Energy's *Shale Gas Subcommittee's 90 Day Report on shale gas and hydraulic fracturing (*August 2011) http://www.shalegas.energy.gov/resources/081811_90_day_report_final.pdf

[37] European Parliament Directorate General for Internal Polices - Department of Economic and Science Policy *Impacts of shale gas and shale oil extraction on the environment and human health* (June 2011) http://www.europarl.europa.eu/document/activities/cont/201107/20110715ATT24183/20110715ATT24183EN.pdf

[38] *Ibid*

The Royal Society and Royal Academy of Engineers study also notes that *'there are concerns that hydraulic fracturing could require volumes of water that would significantly deplete local water resources'.* The report contextualises these concerns noting that:

> *In the UK, under the Water Resources Act 1991, an operator is required to seek an abstraction permit from the environmental regulator if more than 20m3* [5283 US gallons] *of water is to be abstracted*[39] *per day from surface or groundwater bodies. If water is instead sourced from a mains supply, the water company will need to ensure it can still meet the conditions of the abstraction permit that it will already be operating under.*[40]

Further context is provided with the statement:

> *Overall water use is important. Estimates indicate that the amount needed to operate a hydraulically fractured shale gas well for a decade may be equivalent to the amount needed to water a golf course for a month; the amount needed to run a 1,000mw coal fired plant for 12 hours; and the amount lost to leaks in United Utilities' region in north west England every hour.*[41]

These findings are based upon 5m US gallons of water, equivalent to 19,000m^3.[42]

Water use may be minimised by employing specific operational practices such as:

- Recycling wastewater - although it could concentrate contaminants and thereby complicate disposal. This could be minimised by mixing it with fresh water.
- Using alternatives to fresh water – technologies have been developed to use seawater in offshore hydraulic fracture in the US. In some US states the use of salt water from deep aquifers is being considered for onshore drilling.
- Waterless fracturing fluid – including gels, and carbon and nitrogen gas foams. Certain alternatives, such as propane-based LPG, could reduce the toxicity of wastewaters since they do not dissolve salts, heavy metals or Naturally Occurring Radioactive Material (NORM) in shales to the extent that water does.[43]

The report recommends that *'water should be managed in an integrated way'*, more precisely, in the context of minimising water use:

- Techniques and operational practices should be implemented to minimise water use and avoid abstracting water from supplies that may be under stress, and

[39] In this sense abstracted is used to refer to the process of taking water from a source. It could alternatively be called water extraction.

[40] The Royal Society and Royal Academy of Engineers *Shale gas extraction in the UK: a review of hydraulic fracturing* (June 2012) http://royalsociety.org/uploadedFiles/Royal_Society_Content/policy/projects/shale-gas/2012-06-28-Shale-gas.pdf

[41] *Ibid*

[42] Policy Exchange Gas Works *Shale gas and its policy implications* (February 2012) http://www.policyexchange.org.uk/images/publications/gas%20works%20-%20feb%2012.pdf

[43] The Royal Society and Royal Academy of Engineers *Shale gas extraction in the UK: a review of hydraulic fracturing* (June 2012) http://royalsociety.org/uploadedFiles/Royal_Society_Content/policy/projects/shale-gas/2012-06-28-Shale-gas.pdf

- Wastewater should be recycled and reused where possible.[44]

The RoI EPA/University of Aberdeen paper adds to the debate by noting not only that *'local extraction of water from small catchments could have an impact on the ecology and hydrology of rivers in these areas,* but that *'environmental impacts may also develop from transporting water in to the drilling site from further afield: construction of new roads to remote drilling sites and increased heavy road traffic and pollution'.*[45]

2.1c Waste water disposal

Hydraulic fracture works by injecting fracturing fluid into geological formations at high pressure. Releasing this pressure results in '*flowback*', where fracturing fluid, methane, other compounds and additional water from the deposit return to the surface. There is a degree of debate as to how much liquid returns to the surface, according to the European Parliament study industry experts estimate it to be between 20% and 50% of the original water used, while other experts estimate it to be between 9% and 35%.[46] The Joint Academies study includes a much broader estimated range of between 25% and 75%.[47] This uncertainty is attributed to a number of variables:

> *The volume of flowback water depends on the properties of the shale, the fracturing design and the type of fracturing fluid used.*[48]

Moreover, the study also notes:

> *Produced water will continue to return to the surface over a well's lifetime. These wastewaters typically contain salt, natural organic and inorganic compounds, chemical additives used in fracturing fluid and NORM* [Naturally Occurring Radioactive Material]*…*
>
> *Very little is currently known about UK shales to explain what fraction of fracture fluid will return as flowback water, as well as the composition of formation waters and produced water.*[49]

Whilst the volume of waste water is significant, a more pressing matter in the literature examined is what to do with this by-product. As noted in the University of Aberdeen paper:

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[44] *Ibid*

[45] The University of Aberdeen *Fracking: Current Knowledge and Potential Environmental Impacts* (May 2012) http://www.epa.ie/downloads/pubs/research/sss/UniAberdeen_FrackingReport.pdf

[46] European Parliament Directorate General for Internal Polices - Department of Economic and Science Policy *Impacts of shale gas and shale oil extraction on the environment and human health* (June 2011) http://www.europarl.europa.eu/document/activities/cont/201107/20110715ATT24183/20110715ATT24183EN.pdf

[47] The Royal Society and Royal Academy of Engineers *Shale gas extraction in the UK: a review of hydraulic fracturing* (June 2012) http://royalsociety.org/uploadedFiles/Royal_Society_Content/policy/projects/shale-gas/2012-06-28-Shale-gas.pdf

[48] *Ibid*

[49] *Ibid*

> *Active and regulated management of waste water from the fracking process is critical, as this fluid poses one of the greatest tangible risks to the environment.*[50]

According to the Committee for Energy and Climate Change, there are five possible ways to manage waste water:

- Inject it underground through a disposal well (either onsite or offsite;
- Discharge into a nearby surface water body;
- Transport it to a municipal water treatment plant;
- Transport it to a commercial treatment plant; and
- Reuse the water for future fracturing, either with or without treatment.[51]

Summarising the experience in the US, the Royal Society and Royal Academy of Engineers paper states:

> *Some states are requiring operators to formulate disposal plans. In some states, disposal is primarily by underground injection. In others with less suitable subsurface conditions disposal is via discharge into publically owned treatment works. Other states require pre-treatment before discharge. In some shale gas areas, wastes from multiple well sites are managed at a centralised disposal site.*[52]

In addition to the liquid waste, it is possible that dissolved NORMs (Naturally Occurring Radioactive Material) in the waste water may *'settle out to form solid wastes'*, these solid wastes take the form of mineral scale. It should be noted too, however, that:

> *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 mining industries, such as coal and potash.*[53]

Furthermore:

> *Much work has been carried out globally on monitoring levels of radioactivity and handling NORMs in the oil and gas industries. For example, it is standard practice to sandblast pipes to remove scale or to use a rotating drill bit. The removed scale is then placed into sealed containers for later disposal.*[54]

[50] The University of Aberdeen *Fracking: Current Knowledge and Potential Environmental Impacts* (May 2012) http://www.epa.ie/downloads/pubs/research/sss/UniAberdeen_FrackingReport.pdf

[51] The House of Commons Committee on Energy and Climate Change *Shale Gas Report* (May 2011) http://www.publications.parliament.uk/pa/cm201012/cmselect/cmenergy/795/795.pdf

[52] The Royal Society and Royal Academy of Engineers *Shale gas extraction in the UK: a review of hydraulic fracturing* (June 2012) http://royalsociety.org/uploadedFiles/Royal_Society_Content/policy/projects/shale-gas/2012-06-28-Shale-gas.pdf

[53] *Ibid*

[54] *Ibid*

From a UK perspective, the House of Commons Committee for Energy and Climate Change has recommended that:

- DECC and DEFRA ensure that the Environment Agency monitors randomly the flowback and produced water from unconventional gas operations for potentially hazardous material that has been released from the shale formation; and
- The Government to insist that as the shale gas industry develops, companies are required to work together in order to optimize the use of waste water treatment plants, to minimise both the number of plants and the distance waste water has to be transported (the latter becoming significant when a lifecycle assessment of greenhouse gas emissions is considered, further details are below).[55]

The Joint Academies paper recommends that:

- Wastewater should be recycled and reused wherever possible;
- Options for treating and disposing of waste should be planned from the outset. The construction, regulation and siting of any future onshore disposal wells need further investigation.[56]

2.2 Greenhouse Gas Emissions

The product from shale gas production, natural gas *'offers a number of environmental benefits over other sources of energy, particularly other fossil fuels'.* [57] The environmental benefit most often highlighted occurs when natural gas is used to displace coal (in power plants for example), as the former has a lower carbon content than the latter.

Assessing greenhouse gas emissions becomes more complicated when process is considered rather than the product. The IEA and others note that the issue of greenhouse gas emissions from shale and other unconventional gas sources is controversial and the subject of continued debate:

> *Some authors (Howarth, 2011) have argued that emissions from using natural gas as a source of primary energy have been significantly underestimated, particularly for unconventional gas. It has even been argued that full life-cycle emissions from unconventional gas can be higher than from coal. The main issue revolves around methane emissions not only during production, but also during transportation and use of natural gas.*

[55] The House of Commons Committee on Energy and Climate Change *Shale Gas Report* (May 2011) http://www.publications.parliament.uk/pa/cm201012/cmselect/cmenergy/795/795.pdf

[56] The Royal Society and Royal Academy of Engineers *Shale gas extraction in the UK: a review of hydraulic fracturing* (June 2012) http://royalsociety.org/uploadedFiles/Royal_Society_Content/policy/projects/shale-gas/2012-06-28-Shale-gas.pdf

[57] The US Department of Energy *Modern Shale Gas development in the US - a Primer* (2009) http://www.netl.doe.gov/technologies/oil-gas/publications/epreports/shale_gas_primer_2009.pdf

Similarly, According to the US Department of Energy the 'exploration and production of shale gas may include a variety of potential air emission sources that change depending on the phase of operation'. The Department's Shale Gas Subcommittee, provides more detail:

> *Shale gas production, including exploration, drilling, venting/flaring, equipment operation, gathering, accompanying vehicular traffic, results in the emission of ozone precursors (volatile organic compounds (VOCs), and nitrogen oxides), particulates from diesel exhaust, toxic air pollutants and greenhouse gases (GHG), such as methane.*

The Committee noted that as shale gas development has expanded across the US, concern about these emissions has increased at all levels – local, regional and national.

A life-cycle analysis may provide a more accurate picture of the greenhouse gas footprint of shale gas. Such an analysis would consider the production of greenhouse gases throughout the various stages of a fuel's life-cycle. To calculate the life-cycle emissions of shale gas it would be necessary to consider emissions occurring during exploration, production, transport and the burning of the end product. As such, the assumptions made during a life-cycle analysis may considerably impact the results. On this the European Parliament notes:

> *Depending on the assumptions chosen, tight and shale gas at the lower end has similar overall GHG* [greenhouse gas] *emissions as conventional natural gas transported over long distances, or at the upper end has GHG emissions close to hard coal.*[58]

The US Department of Energy Shale Gas Subcommittee believes that the evidence base on shale gas' life-cycle analysis is lacking:

> *There have been relatively few analyses done of the question of the greenhouse gas footprint over the entire fuel-cycle of natural gas production, delivery and use, and little data are available that bear on the question.*

Furthermore, they argue that more work is required to assess how the life-cycle emissions of shale gas compare to those of other fuels:

> *The Subcommittee believes that additional work is needed to establish the extent of the footprint of the natural gas fuel cycle in comparison to other fuels used for electric power and transportation because it is an important*

[58] European Parliament Directorate General for Internal Polices - Department of Economic and Science Policy *Impacts of shale gas and shale oil extraction on the environment and human health* (June 2011) http://www.europarl.europa.eu/document/activities/cont/201107/20110715ATT24183/20110715ATT24183EN.pdf

> *factor that will be considered when formulating policies and regulations affecting shale gas development.*[59]

As such, they recommend that a *'cradle-to-grave'* emissions assessment of shale gas be carried out.

The Subcommittee add the following caveat:

> *Designing and executing a comprehensive greenhouse gas footprint study based on actual data – the Subcommittee's recommended approach -- is a major project. It requires agreement on measurement equipment, measurement protocols, tools for integrating and analysing data from different regions, over a multiyear period. Since producer, transmission and distribution pipelines, end-use storage and natural gas many different companies will necessarily be involved. A project of this scale will be expensive. Much of the cost will be borne by firms in the natural gas enterprise that are or will be required to collect and report air emissions.*[60]

A significant sub-issue often dominates the literature's discussion of greenhouse gas emissions. That is the potential impact of methane emissions. The primary component of natural gas is methane.[61] Methane is a *'more potent greenhouse gas than* CO_2*'*[62], although its short lifespan ensures that its potency diminishes over time:

> *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* [63]

Concerns around methane emissions focus on emissions which occur during the fracturing process. There are a number of circumstances in which methane may be emitted:

- Through the intentional venting of gas for safety or economic reasons;
- Through leaks in pipelines, valves or seals – so called fugitive emissions;
- Through the rupture of confining equipment such as pipelines and pressurised tanks; and
- Due to the incomplete burning in gas flares[64].[65]

[59] *Ibid*
[60] *Ibid*
[61] The US Department of Energy *Modern Shale Gas development in the US - a Primer* (2009) http://www.netl.doe.gov/technologies/oil-gas/publications/epreports/shale_gas_primer_2009.pdf
[62] The International Energy *Golden Rules for a Golden Age of Gas* (May 2012) http://www.worldenergyoutlook.org/media/weowebsite/2012/goldenrules/WEO2012_GoldenRulesReport.pdf
[63] The Royal Society and Royal Academy of Engineers *Shale gas extraction in the UK: a review of hydraulic fracturing* (June 2012) http://royalsociety.org/uploadedFiles/Royal_Society_Content/policy/projects/shale-gas/2012-06-28-Shale-gas.pdf
[64] The effectiveness of burning in gas flares depends on wind and other conditions. A comparison is drawn to the lighting of a gas cooker, where it can take a few seconds before a steady flame is established, during which time *'un-burnt'* gas escapes.
[65] The International Energy *Golden Rules for a Golden Age of Gas* (May 2012) http://www.worldenergyoutlook.org/media/weowebsite/2012/goldenrules/WEO2012_GoldenRulesReport.pdf

There is debate regarding the level of methane emissions which occur during the process of shale gas extraction. Moreover, there is further debate on how methane emissions from unconventional gas compare to those from conventional gas. Methane emissions remain significant however, as high-levels of emissions due to fracturing operations could lead to the gas secured through those operations having a higher net greenhouse gas footprint than other fuel types.[66]

Two issues arise from the consideration of methane within the shale gas life cycle. Firstly, it highlights that further work is required to fully understand the levels of methane (and other types of) emission which occur due to shale gas production and to also establish how these compare to conventional gas and to the overall greenhouse gas footprint of other fuels. This was a concern of the US Department of Energy Subcommittee on Shale Gas, who recommended:

> *…enlisting a subset of producers in different basins, on a voluntary basis, to immediately launch projects to design and rapidly implement measurement systems to collect comprehensive methane and other air emissions data.*
>
> *These pioneering data sets will be useful to regulators and industry in setting benchmarks for air emissions from this category of oil and gas production, identifying cost-effective procedures and equipment changes that will reduce emissions; and guiding practical regulation and potentially avoid burdensome and contentious regulatory procedures. Each project should be conducted in a transparent manner and the results should be publicly disclosed.*[67]

A second issue arising from potential methane emissions is how they might be mitigated. Monitoring emissions before (to establish levels of natural seepage), during and after operations would allow operators to identify potential problems and local air quality standards are not breached. In the US, *'green completion'* technologies allow produces to capture and then sell excess methane rather than venting or flaring it. Utilising *'green completion'* technology could enable emissions levels similar to those associated with conventional natural gas. The US EPA has issued regulations which will make green completions mandatory from 2015 onwards.[68] According to the Joint Academies study:

> *No such requirements exist in the UK for exploratory activities. Consideration should be given the possible use of green completion*

[66] The University of Aberdeen *Fracking: Current Knowledge and Potential Environmental Impacts* (May 2012) http://www.epa.ie/downloads/pubs/research/sss/UniAberdeen_FrackingReport.pdf

[67] The US Department of Energy – Shale Gas Subcommittee of the Secretary of Energy Board Advisory Board Shale Gas Production *90 day report* (August 2011) http://www.shalegas.energy.gov/resources/081111_90_day_report.pdf

[68] The Royal Society and Royal Academy of Engineers *Shale gas extraction in the UK: a review of hydraulic fracturing* (June 2012) http://royalsociety.org/uploadedFiles/Royal_Society_Content/policy/projects/shale-gas/2012-06-28-Shale-gas.pdf

technologies, especially for any future production activities in the UK, based on best available technologies and operational best practices.[69]

2.3 Well integrity

Given that the above discussions on water contamination and air pollution both noted that leakages are a potential source of contamination the issue of well integrity is significant. The Royal Society and Royal Academy of Engineers study, for example, states that *'integrity must remain the highest priority to prevent contamination'.* It adds however, that *'probability of well failure is low for a single well if it is designed, constructed and abandoned according to best practice'.*[70]

There are three possible types of well failure identified by the join report:

- Blowouts – a sudden and uncontrollable escape of fluids from a well;
- Annular leaks – in which contaminants move vertically through the well due to poor cementation; and
- Radial leaks – in which contaminants move out of the well horizontally into surrounding rock formations due to casings failure.

The report makes five recommendations which could ensure well integrity is maintained:

- 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; and,
- The results of well tests and the reports of well examinations should be submitted to the Department of Energy and Climate Change.

The IEA's Golden Rules for a Golden Age of Gas also recommends that wells conform to standards and that they are inspected. It states that policy make should:

> *Put in place robust rules on well design, construction, cementing and integrity testing as part of a general performance standard that gas bearing formations must be completely isolated from other strata penetrated by the well, in particular freshwater aquifers.*[71]

[69] *Ibid*
[70] *Bid*
[71] The International Energy *Golden Rules for a Golden Age of Gas* (May 2012) http://www.worldenergyoutlook.org/media/weowebsite/2012/goldenrules/WEO2012_GoldenRulesReport.pdf

It also recommends that they:

> *Consider appropriate minimum-depth limitations on hydraulic fracturing to underpin public confidence that this operation takes place only well away from the water table.*[72]

2.4 Potential geological impacts of drilling

This section groups together a number of considerations within the literature assessed under the broad heading *'impacts of drilling'.* Specifically, the section will look the potential for fracture propagation and seismic activity.

2.4a Facture propagation

Fracture propagation refers to the growth of fractures. The RoI EPA paper notes that:

> *It is important to recognise that the fracking process of pumping large volumes of water into a borehole at a certain depth cannot control the type of fractures that are created or reactivated. The array of fractures created and/or reactivated or reopened depends on a complex interplay of the in situ stress, the physical properties of the local rock volume and any pre-existing fractures, and the pore fluid pressure.*[73]

However, according to the Joint Academies it is within a developer's interests to ensure that fractures are controlled and carefully monitoring, as:

> *Excessive, uncontrolled fracture growth is uneconomic, wasting resources on the extra chemicals, pumping equipment and manpower needed.*[74]

The potential risks of uncontrolled fracture propagation include water contamination and seismic activity (for further details of the latter see the section that follows).[75] As with the other risks addressed in the literature, methods mitigation and monitoring may be employed to reduce fracture propagation. These include:

- Monitoring fracture growth with chemical tracers, tiltmeters or seismometers;
- Controlling pressure of fluid injection; and,
- Understanding the geology of the shale.[76]

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[72] *Ibid*

[73] The University of Aberdeen *Fracking: Current Knowledge and Potential Environmental Impacts* (May 2012) http://www.epa.ie/downloads/pubs/research/sss/UniAberdeen_FrackingReport.pdf

[74] The Royal Society and Royal Academy of Engineers *Shale gas extraction in the UK: a review of hydraulic fracturing* (June 2012) http://royalsociety.org/uploadedFiles/Royal_Society_Content/policy/projects/shale-gas/2012-06-28-Shale-gas.pdf

[75] The University of Aberdeen *Fracking: Current Knowledge and Potential Environmental Impacts* (May 2012) http://www.epa.ie/downloads/pubs/research/sss/UniAberdeen_FrackingReport.pdf

[76] The Royal Society and Royal Academy of Engineers *Shale gas extraction in the UK: a review of hydraulic fracturing* (June 2012) http://royalsociety.org/uploadedFiles/Royal_Society_Content/policy/projects/shale-gas/2012-06-28-Shale-gas.pdf

2.4b Seismic activity

The European Parliament report states that it is *'well known that hydraulic fracturing can induce small earthquakes in the order of 1-3 at the Richter scale'.* The report cites a number of examples:

- Fort Worth, Texas experienced 18 small earthquakes since 2008;
- The city of Cleburne, Texas experienced nine earthquakes between June and July 2009, in an area that had registered no earthquakes in the previous 140; and,
- Blackpool UK, which experienced a 1.5 at the Richer scale in April 2011, followed by a 2.5 Richer scale in June of the same year.[77]

Of the papers examined Joint Academies study provides the most detailed examination of seismic activity. The study notes that seismicity in the UK is low by global standards, with the largest seismic events likely to register a magnitude of less than five on the Richter scale. Most seismic activity in the UK occurs at depths of over 10km, which limits the extent to which they are felt on the surface.[78]

The UK has also experienced seismic activity as a result of coal mining, this activity is noted to be smaller than naturally occurring seismic activity.

According to the report hydraulic fracturing can cause two types of seismic activity:

- Microseismic events: which are 'a routine feature of hydraulic fracturing and are due to the propagation of engineered fractures'; and
- Larger seismic events which are 'generally rare but can be induced by hydraulic fracturing in the presence of a pre-stressed fault'.[79]

Commenting on the events which occurred 2011, the report notes that Blackpool is an *'area of low seismic activity even by UK standards'*. Drawing on the Department of Energy and Climate Change commissioned investigation into the events, the report states:

> *The most likely cause of the events was the transmission of injected fluid to a nearby (but previously unidentified) pre-stressed fault, reducing the effective stress to the point where the fault slipped and released its energy… The energy released was several orders of magnitude greater than the microseismic activity associated with routine hydraulic fracturing.*[80]

The report adds:

[77] European Parliament Directorate General for Internal Polices - Department of Economic and Science Policy *Impacts of shale gas and shale oil extraction on the environment and human health* (June 2011) http://www.europarl.europa.eu/document/activities/cont/201107/20110715ATT24183/20110715ATT24183EN.pdf

[78] The Royal Society and Royal Academy of Engineers *Shale gas extraction in the UK: a review of hydraulic fracturing* (June 2012) http://royalsociety.org/uploadedFiles/Royal_Society_Content/policy/projects/shale-gas/2012-06-28-Shale-gas.pdf

[79] *Ibid*

[80] *Ibid*

In the absence of further data it is difficult to determine whether the fault was directly intersected by the well, or whether hydraulic fracturing led to pressure changes that induced a distant fault to slip. Subsequent geomechanical tests suggest that bedding planes in the Bowland shale are weak enough to have slipped and provide a conduit for fluid to flow out of the well and into the fault zone.[81]

The report recommends actions to mitigate seismic activity. In the first instance it recommends geological surveys to characterise stresses and identify faults, because:

In many areas of the UK, only the largest faults have been identified, and then only at the surface. Predicting the presence of subsurface faults requires detailed surface mapping, development of validated geological models, and if available data from seismic reflection surveys.[82]

It is recommended that the British Geological Survey or another appropriate body carry out national surveys throughout the UK. Furthermore, once faults have been identified and stresses characterised:

…operators can draw on well-understood tools used in the oil and gas mining industries to assess the orientation and slip tendency of faults and bedding plans… Hydraulic fracturing near a fault with a high slip tendency should be avoided.[83]

In addition to national surveys the report recommends that a pre-fracturing injection test be introduced and a traffic light monitoring system be adopted. A pre-fracturing injection test with mircoseimic monitoring can help establish the fracture behaviour of a particular formation and allow future activity to be adjusted accordingly.

The recommended traffic light monitoring system could, the report argues, be adapted from that utilised by Enhanced Geothermal Systems. A traffic light monitoring system would collect data on seismic activity on a well an outline a specific actions to follow once certain levels of seismicity are reached. As an example it cites the following:

- Green – magnitude smaller than 0 – injection proceeds as planned;
- Amber – magnitude between 0 and 1.7 – injection proceeds with caution monitoring is intensified; and
- Red – magnitude greater than 1.7 – injection is immediately suspended.[84]

The report points out, however, that:

Traffic light monitoring systems are limited by the need for, and expense of real-time seismic data. These systems also rely on the extrapolation of

[81] *Ibid*
[82] *Ibid*
[83] *Ibid*
[84] *Ibid*

statistical relationships observed in natural seismicity that may not necessarily apply to induced seismicity. More research is needed to better understand the precise relationship between well pressure and seismicity in shales.[85]

Finally, the report recommends that DECC:

…should consider how induced seismicity should be regulated. Operators should share data with DECC and BGS to establish a national database of shale stress properties so that suitable well locations can be identified.[86]

2.5 Land use

Development of shale gas is likely to lead to consumption of landscape *'as rig pads need space for technical equipment, fluid storage and road access'.* This is highlighted by experiences from the US, for example:

By the end of 2010, almost 15,000 wells had been drilled in the Barnett Shale, while the total shale extends over an area of 13,000 km²]. This results in an average well density of 1.15 wells per km².[87]

Furthermore:

The well pads are connected with roads for truck transport, which further increases land consumption. In the USA, surface area is also consumed for waste water ponds collecting the back flowing waste water before it is disposed of or removed by truck or pipe...

… After extraction, the gas must be transported to the distribution grids. As most wells have a small production rate with a steep decline profile, very often the gas is stored at the well pad and periodically loaded on trucks. If the well density is high enough gathering networks with compressor stations are built. Which storage or transport mode is chosen and whether the lines are built above or below ground depends on the specific parameters of the projects and on the applicable regulations. [88]

Land consumption is viewed to have potential environmental and social implications. The former position was summed up by the Campaign to Protect Rural England, in evidence to the Committee for Energy and Climate Change, in stating that they were:

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[85] *Ibid*

[86] *Ibid*

[87] European Parliament Directorate General for Internal Polices - Department of Economic and Science Policy *Impacts of shale gas and shale oil extraction on the environment and human health* (June 2011) http://www.europarl.europa.eu/document/activities/cont/201107/20110715ATT24183/20110715ATT24183EN.pdf

[88] *Ibid*

> *…concerned to ensure that any shale gas extraction in England does not cause unacceptable damage to the countryside…on shore shale gas production…* [is]*… likely to be visually and ecologically intrusive.*[89]

The concluded that production would face:

> *…significant opposition on the grounds of landscape and wildlife conservation and rural character and amenity.*[90]

A further consideration is how land consumption interacts with population density. This was also a concern for the Committee. In England, for example, the population density was calculated to be 383 persons per km^2; in the US it is as low as 27 persons per km^2.

On these issues the Committee concluded:

> *We conclude that the development of the UK shale gas industry will be different from the US—greater population density and stricter environmental legislation in Europe will give a greater incentive to drill fewer, better wells that take advantage of multi-well pad technology and horizontal drilling to minimise the impact on the landscape.*
>
> *We recommend that the Environment Agency and the Department of Energy and Climate Change take lessons from unconventional gas exploration in the US, especially at the state-level where much of the expertise lies. The US has a great deal of regulatory experience of dealing with the issues of water contamination, the volume of water required, waste water treatment and disposal, air pollution, and infrastructure challenges. The UK Government must use this experience to ensure the lowest achievable environmental impacts from unconventional gas exploitation here.*[91]

3 Shale gas resource

As noted in the introduction, the shale resource in the US has revolutionised the gas industry in the country. Between 2001 and 2011 shale gas, as a proportion of the country's natural gas production, rose from 2% to 30%. Estimates predict that shale gas will account for 46% of production by 2035. [92]

Exploiting its shale gas resources has allowed the US to become *'essentially self-sufficient in natural gas, with the only notable imports being from Canada'.* Furthermore the *'the price of natural gas has fallen by more than a factor of two since 2008'.* It is

[89] The House of Commons Committee on Energy and Climate Change *Shale Gas Report* (May 2011) http://www.publications.parliament.uk/pa/cm201012/cmselect/cmenergy/795/795.pdf

[90] *Ibid*

[91] *Ibid*

[92] The US Department of Energy – Shale Gas Subcommittee of the Secretary of Energy Board Advisory Board Shale Gas Production *90 day report* (August 2011) http://www.shalegas.energy.gov/resources/081111_90_day_report.pdf

anticipated that the *'domestic production of shale has also the potential over time to reduce dependence on imported oil'* and that *''international shale gas production will increase the diversity of supply for other nations'.*[93]

Despite the transformation of the energy industry in the US, European and UK estimates of the impact of shale gas remain cautious. Table 1, which is sourced from the European Parliament study, provides a comparison of conventional gas production and reserves to shale gas resources quantified as *gas-in-place* (GIP) and technically recoverable resource (all figures are measured in BCM – billion cubic metres). The table also includes an assumed recovery factor which is the percentage of GIP estimated to be technically recoverable. This figure carries the following caveat:

> *Only a certain share of the technically recoverable shale gas resource will be converted into reserves and produced over time, since further restrictions limit the access to the whole shale. For instance, surface geography, protected areas (e.g. drinking water reservoirs, wild life refuges, national parks) or simply densely populated areas will restrict access to the shales.*[94]

Table 1: Assessment of European conventional gas production and reserves compared to shale gas resources[95]

Country	Production 2009 (BCM)	Proven conventional reserves 2009 (BCM)	Shale Gas GIP 2010 (BCM)	Technically recoverable shale gas resource 2010 (BCM)	Assumed recovery factor 2010
France	0.85	5.7	20,376	5,094	25%
Germany	15.6	92.4	934	226	24.2%
Netherlands	73.3	1,380	1,868	481	25.7%
Norway	103.5	2,215	9,424	2,349	24.9%
UK	59.6	256	2,745	566	20.6%
Denmark	8.4	79	2,604	651	25%
Sweden	0	0	4,641	1,160	25%
Poland	4.1	164	22,414	5,292	23.6%
Lithuania	0.85	0	481	113	23.5%
Total EU 27 & Norway	**266**	**4,202**	**65,487**	**16,470**	**~25%**

Assessing the *'probable relevance of unconventional gas production on European gas supply'*, the European Parliament, drawing on IEA estimates from 2011, states that:

[93] *Ibid*

[94] European Parliament Directorate General for Internal Polices - Department of Economic and Science Policy *Impacts of shale gas and shale oil extraction on the environment and human health* (June 2011) http://www.europarl.europa.eu/document/activities/cont/201107/20110715ATT24183/20110715ATT24183EN.pdf

[95] *Ibid*

> *The development of unconventional gas resources in Europe will probably be led by Poland which is believed to possess 1.4-5.3Tcm* [trillion cubic metres] *of shale gas, predominately in the North. By mid-2011, Poland had already granted 86 licences for exploration of conventional gas.*

Poland also was of interest to the House of Commons Committee on Energy and Climate Change:

> *We conclude that it is important for the UK to monitor the development of shale gas in Poland—the "barometer of Europe" on this issue—both in terms of exploration and regulation. We are concerned that there could be adverse competitive consequences for the UK if Poland unilaterally develops its shale gas resources within the EU, particularly if their energy policy is driven by energy security—in spite of the environmental concerns associated with hydraulic fracturing—owing to their reliance on imported gas.*[96]

The European Parliament report predicted (again drawing on the earlier IEA report):

> *…only a marginal influence of shale gas production for Europe. The average decline of domestic gas production including conventional and unconventional gas is seen as 1.4% per year.*[97]

The report notes, however, the possibility that:

> *…a certain relevant amount of gas could be produced at regional level*[98]

The evidence presented to the House of Commons Committee on Energy and Climate Change led them to conclude:

> *…shale gas resources in the UK could be considerable. However, while they could be sufficient to help the UK increase its security of supply, it is unlikely shale gas will be a 'game changer' in the UK to the same extent as it has been in the US.*[99] [100]

This was further clarified:

[96] The House of Commons Committee on Energy and Climate Change *Shale Gas Report* (May 2011) http://www.publications.parliament.uk/pa/cm201012/cmselect/cmenergy/795/795.pdf

[97] European Parliament Directorate General for Internal Polices - Department of Economic and Science Policy *Impacts of shale gas and shale oil extraction on the environment and human health* (June 2011) http://www.europarl.europa.eu/document/activities/cont/201107/20110715ATT24183/20110715ATT24183EN.pdf

[98] *Ibid*

[99] The House of Commons Committee on Energy and Climate Change *Shale Gas Report* (May 2011) http://www.publications.parliament.uk/pa/cm201012/cmselect/cmenergy/795/795.pdf

[100] On off shore resources the Committee stated that there is substantial evidence that UK offshore unconventional gas resources could dwarf the potential onshore supplies. While these might be economically unviable at present, "uneconomic" reserves can become economic quickly as technology and prices shift. We recommend that DECC encourage the development of the offshore shale gas industry in the UK, working with HM Treasury to explore the impacts of tax breaks to the sector.

Shale gas has the potential to diversify and secure European energy supplies. Domestic prospects—onshore and potentially offshore—could reduce the UK's dependence on imports, but the effect on energy security is unlikely to be enormous. We conclude that energy security considerations should not be the main driver of policy on the exploitation of shale gas.[101]

On the impact on gas prices the report found:

...that a glut in shale gas production could drive the price of conventional gas down, but there is uncertainty as to the extent of this. If there were to be a fall in prices it is unlikely to be as dramatic as that seen in the US

The Commons Committee cite work by the Department of Energy and Climate Change to identify differences between onshore shale gas development in the US to the UK, Europe and the rest of the world:

- There is lack of production experience outside of the US, resulting in uncertainties about the extent to which available resources can be exploited;
- The gas price required to incentivise investment will depend on the productivity and cost of the well;
- Europe has a developed regulatory framework (further details below);
- Europe has a high population density compared to the US;
- US grants land owners rights over hydrocarbon resources rather than vesting it in the state;
- Developing economies have poor gas infrastructure; and,
- Unconventional exploration technology and expertise is generally confined to the US.[102]

The depletion rate of shale gas production was also of concern to the Commons Committee. They note two opposing views on this the optimistic view, commonly held view:

…that the decline curve of shale gas wells flattens out over time, but maintains a low level of production for a significant period.[103]

And the pessimistic view that:

…production will fall to small levels relatively quickly.

Speaking to the Committee, shale gas developer Cuardilla (who are of the optimistic view) stated that the:

[101] *Ibid*
[102] *Ibid*
[103] *Ibid*

> *…only scientific method currently available to estimate these* [depletion rates] *factors for UK shale gas is by analogy to commercial North American shale plays.*[104]

Adding that:

> *…long-term shale gas production decline rates remain prediction rather than fact.*[105]

Cuadrilla estimate:

> *…in common with other unconventional gas wells, [a typical shale gas well] will witness steep early production decline rates—typically of around 30% to 40% for one to two years—followed by up to 50 years of commercial life at low decline rates, typically 5% to 7%.*[106]

In their evidence to the Committee, OFGEM noted that experience from the US indicated that re-fracturing of wells could improve depletion rates.

On the pessimistic view, the Committee states that this *'raises the spectre of abandoned well heads scattered over the landscape'.* They concluded:

> *In the crowded UK we cannot afford to risk the creation of contaminated and abandoned sites where shale gas production has stopped. The prospect of such a risk must be carefully considered when licences and other permissions are granted. We recommend that DECC should require that a fund be established to ensure that if wells are abandoned they can be "plugged". Such a fund could be established through a levy on shale gas well drilling or an upfront bond.*[107]

To which the government responded:

> *In England and Wales, in the event that a permit is required under the Environmental Permitting Regulations 2010 for certain activities at the surface, such as large scale refinement or combustion, controls would be in place to require site restoration in the event that the activity led to the site becoming contaminated… In Scotland equivalent regulatory controls exist to ensure environmental damage caused by permitted sites is remediated prior to permit surrender.*[108]

[104] *Ibid*
[105] *Ibid*
[106] *Ibid*
[107] *Ibid*
[108] House of Commons Energy and Climate Change Committee *Shale Gas: Government Response to the Committee's Fifth Report of Session 2010–12* (19 July 2012) http://www.publications.parliament.uk/pa/cm201012/cmselect/cmenergy/1449/1449.pdf

4 Shale gas production and renewable development

The European Parliament paper, the House of Common's report and the Joint Academies report include an analysis on how shale gas development might impact on the push for renewables.

The Joint Academies report summarises the wider debate:

> *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*[109]

On this matter the European Parliament adopted a cautionary tone:

> *Whatever reasons for allowing hydraulic fracturing exist, the justification that it helps to reduce greenhouse gas emissions are rarely among them. On the contrary, it is very likely that investments in shale gas projects – if at all – might have a short-living impact on gas supply which could be counterproductive, as it would provide the impression of an ensured gas supply at a time when the signal to consumers should be to reduce this dependency by savings, efficiency measures and substitution.*[110]

The House of Commons Committee report stated that:

> *Conventional sources of natural gas in the North Sea are diminishing. We conclude that if a significant amount of shale gas enters the UK market (whether from domestic sources, imported from another European country, or from the global market via LNG) it will probably discourage investment in more-expensive—but lower carbon—renewables. The UK needs to manage this risk in order to achieve its aim of generating more electricity from renewable and other low carbon sources This could be done through the progressive implementation of an Emissions Performance Standard (EPS) that would prevent gas power stations operating as base load providers after a certain date unless fitted with carbon capture and storage.*[111]

Concluding that:

[109] The Royal Society and Royal Academy of Engineers *Shale gas extraction in the UK: a review of hydraulic fracturing* (June 2012) http://royalsociety.org/uploadedFiles/Royal_Society_Content/policy/projects/shale-gas/2012-06-28-Shale-gas.pdf

[110] European Parliament Directorate General for Internal Polices - Department of Economic and Science Policy *Impacts of shale gas and shale oil extraction on the environment and human health* (June 2011) http://www.europarl.europa.eu/document/activities/cont/201107/20110715ATT24183/20110715ATT24183EN.pdf

[111] The House of Commons Committee on Energy and Climate Change *Shale Gas Report* (May 2011) http://www.publications.parliament.uk/pa/cm201012/cmselect/cmenergy/795/795.pdf

> *… shale gas has the potential to shift the balance in the energy markets that the Department has tried to create away from low carbon electricity generation. We recommend that the Department take account of the impact of shale gas in its decisions on reform of the electricity market and its expectations of future investment in the energy industry.*[112]

The Government's response to these conclusions argued that fossils fuels would continue to play an important role in future energy markets, with gas in particular helping to provide the flexibility needed to integrate renewables onto the system. As such they believed it was essential that investment in gas generation was not undermined and investors were provided with sufficient certainty.[113]

On the Electricity Market Reform recommendation they responded:

> *The modelling shows that the effect of electricity market reform (EMR), in particular the Carbon Price Floor and the Feed-in-Tariff for low carbon generation, will be an increase in low carbon forms of generation, including nuclear, renewables and CCS. The proposals are tested against a range of fossil fuel prices (including low gas prices up to 2030) to assess their robustness to changing assumptions. We are confident that EMR will create a framework that will ensure we can meet our renewable and carbon emissions reduction targets.*[114]

5 Discussion

The following section provides a brief discussion of the points raised above, looking first at environmental considerations.

5.1 Environmental concerns

Water contamination: the contamination of water in general and of drinking water in particular is a major concern. Individual incidents of water contamination from fracturing fluid (Pavillion) and from methane (northern Pennsylvania) have been recorded (although the results of the former study are still being debate).

Importantly, significant studies into the relationship between hydraulic fracturing and water contamination are on-going. Most notably the US EPA's investigation into the *Potential Impact of Hydraulic Fracturing on Drinking Water Resources*, due for publication in draft form in 2012.

Analysing the US experience from the outside has led notable European and UK bodies (the European Parliament, the House of Commons Committee of Energy and

[112] *Ibid*

[113] House of Commons Energy and Climate Change Committee Shale Gas: Government Response to the Committee's Fifth Report of Session 2010–12 (19 July 2012) http://www.publications.parliament.uk/pa/cm201012/cmselect/cmenergy/1449/1449.pdf

[114] *Ibid*

Climate Change, and the Joint Academies) to conclude that it is not hydraulic fracture, rather the improper application of the method that may lead to the contamination.

As such there is an apparent confidence within these bodies that a mixture of regulation and monitoring could mitigate the risk of contamination.

The University of Aberdeen paper, commissioned by the RoI EPA recommend that research and development of chemical free fracturing fluid should continue. Such a development could see the risk of contamination greatly reduced, although the potential for contamination due to methane migration would still be a factor.

Water consumption: the evidence examined agrees that hydraulic fracturing requires large quantities of water. There is, however, no definitive figure on what volume is required, due to variations between specific wells and shales. Moreover, there is debate over how water use in hydraulic fracturing compares to conventional gas extraction.

The major concern with regard to water consumption is that hydraulic fracturing could lead to the depletion of local water supplies. The Joint Academies paper puts water consumption into context arguing that the volume of water used in hydraulic fracturing over a decade (which they argue is 19,000m^3) is broadly comparable to the amount needed to water a golf course, power a 1000mw coal fired power plant for 12 hours, or the amount lost in leaks by United Utilities’ in North West England every hour.

Despite these comparisons it could be argued that hydraulic fracturing could add increased pressure onto an already strained system. Consideration should also be given to the likely need for multiple wells all requiring large quantities to operate.

Minimising the pressure on local water systems could become a significant factor. Some possible methods have been outlined in the literature, namely recycling waste waters, using alternatives to fresh water and developing waterless fracturing fluid.

A further consideration with regard to water consumption is how the need to provide large quantities for fresh water to wells might interact with local infrastructure and, should it be transported by road, with emissions levels.

Waste water: there is debate within the literature as to what proportion of fracturing fluid returns to the surface as waste water. Estimates vary from between 9% and 35% and from between 25% and 75%.

A more pressing issue, however, is what might be done with this waste fluid which could potentially contain salt, natural organic and inorganic compounds, chemical additives used in fracturing fluid and NORM. According to the Joint Academies, very little is known about UK shales to explain the level of water that might be returned and what that water might contain. These factors are likely to influence how waste water managed.

From a UK perspective the Joint Academies paper recommends that waste water is recycled wherever possible, which would also help mitigate pressure on local water supplies. The Joint Academies recommends that waste water management plans are developed at an early stage, whilst the House of Commons Committee recommended that the industry works together to optimise waste water treatment facilities.

Greenhouse gas emissions: considerable debate exists around the greenhouse gas footprint of shale gas. The debate is nuanced and considers factors such as how the emissions of the shale gas compare to other fuels, how shale gas compares to other fuels on a life-cycle analysis and what role methane emissions play in the overall assessment of shale gas' emissions levels.

What is evident from the literature surveyed is that a *'cradle-to-grave'* analysis of emissions levels, which considers factors such as the burning of the final product, emissions during extractions and emissions during transportation, is yet to be completed. Such a study would likely allow for better understanding of the potential impact of shale gas development, however, cost has been identified as a major constraint. The most appropriate place for such a study would appear to be the US, given the more developed shale gas industry there.

The evidence assessed highlights that emissions mitigation is likely to be a key consideration for the industry and policy makers. According to the Joint Academies report thought should be given to carrying out emissions monitoring before, during and after drilling operations. Further consideration may also be given to following the US's lead in making green completion techniques mandatory.

Well integrity: ensuring well integrity was highlighted in one study as the *'highest priority to prevent contamination'.* There is agreement within the literature that consideration be given how wells are monitored and what minimum standards should be imposed.

Fracture propagation: uncontrolled fracture propagation may increase the risk of water contamination and seismic activity. The literature suggests that it is in the economic interests of developers to control fracture growth. Mitigation and monitoring are key to reducing unwanted or uncontrolled propagation.

Seismic activity: there is agreement in the literature that hydraulic fracturing can lead to seismic activity. It can be caused by the propagation of fractures, or through fracturing a pre-stressed fault. The evidence suggests that more can be done to *'characterise stresses and identify faults'* throughout the UK, and a process of national surveys has been recommended. This, it is argued would enable the positioning of wells on the most suitable location. How seismic activity is monitored throughout a well's life is a further consideration arising from this discussion.

Land-consumption: shale gas production is likely to lead to consumption of land for well development, water storage and transport. This has the potential to lead to ecological, visual and other disruption. A particular concern for the House of Commons Committee was how land use interacts with population density. The Committee compares the UK's population density of 383 persons per km^2 to the US, where population density is as low as 27 persons per km^2. From a Northern Ireland perspective, according to NISRA, the overall population density in 2010 was 132.5 persons per km^2, for Fermanagh it was 37.1 persons per km^2.[115]

5.2 Resources

Turning to the resource considerations the studies examined suggest that despite the transformation of the US gas industry prompted by the development of shale gas there, the European Parliament is cautious over how much impact the resources available in Europe will have on European energy markets. They have predicted only a marginal impact. The House of Commons Committee on Energy and Climate Change argue that while the UK resources are likely to be considerable and could increase security of supply the impact of shale gas is unlikely to be a game changer. This finding applies to both the level of resource and impact (or lack thereof) this resource has on energy prices.

Other issues arising from this section include:

- Only a proportion of gas within a shale formation is technically recoverable. In the UK this is estimated to be just over 20%;
- There is debate over the depletion rate of shale gas, with optimistic and pessimistic views expressed. The resolution of this debate may enable a better understanding of the long-term impacts of shale gas exploration upon energy resources and prices;
- A number of factors influencing successful development in the US and potentially absent in other regions were identified. These included production experience; gas prices and their relation to investment outlays; regulatory frameworks; population densities; land owner rights; gas and other infrastructure; and availability of exploration technology.

5.3 Relationship to renewable development

The literature has raised concerns over whether shale gas exploration could displace renewable development. These concerns are interlinked with the debate on greenhouse gases and whether shale gas is to be a transition fuel or whether it, as stated in the Joint Academies paper, locks countries into a fossil fuel economy.

Countering this is the UK government's assertion that fossil fuels will continue to play an important part in the energy mix as renewable energy comes on-stream, enabling the integration of intermittent resources.

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[115] NISRA *Population density 1981 – 2010* (accessed 23 August 2012) http://www.nisra.gov.uk/archive/demography/population/LGD_Pop_Densities(1981-2010).xls

The impact shale gas exploration will have on Northern Ireland's renewable generation development and the energy mix in general is likely to be determined by the availability of the resource and whether it can be economically extracted.

5.4 Other considerations

The importance of monitoring has been raised throughout this paper in connection with emissions, water contamination and seismic activity. The literature examined also highlights the importance of sharing data with the public. For example, the US Department of Energy Subcommittee states:

> *The Subcommittee believes there is great merit to creating a national database to link as many sources of public information as possible with respect to shale gas development and production. Much information has been generated over the past ten years by state and federal regulatory agencies. Providing ways to link various databases and, where possible, assemble data in a comparable format, which are now in perhaps a hundred different locations, would permit easier access to data sets by interested parties.*
>
> *Members of the public would be able to assess the current state of environmental protection and safety and inform the public of these trends. Regulatory bodies would be better able to assess and monitor the trends in enforcement activities. Industry would be able to analyse data on production trends and comparative performance in order to identify effective practices.*[116]

Transparency is viewed as key to reducing public concern. Extending transparency to disclosing the chemicals in fracturing fluid is also recommended by the Subcommittee.[117] Furthermore early involvement of the public in the decision making process was viewed by the Joint Academies as a way in which *'public frustration'* could be reduced.[118]

As noted in the introduction, the development of shale gas is a relatively young phenomenon. Because of this what is considered best practice is likely to evolve. This suggests the need for continued research and development into the process used during development. One example previously cited is that of chemical free fracturing fluid.

[116] The US Department of Energy – Shale Gas Subcommittee of the Secretary of Energy Board Advisory Board Shale Gas Production *90 day report* (August 2011) http://www.shalegas.energy.gov/resources/081111_90_day_report.pdf

[117] *Ibid*

[118] The Royal Society and Royal Academy of Engineers *Shale gas extraction in the UK: a review of hydraulic fracturing* (June 2012) http://royalsociety.org/uploadedFiles/Royal_Society_Content/policy/projects/shale-gas/2012-06-28-Shale-gas.pdf

5.5 Conclusions

A review of the selected literature identifies a range of risks associated with the exploration of shale gas and with hydraulic fracturing. These risks are largely environmental and concern the interaction with water supplies, greenhouse gas emissions, seismic activity, and land consumption. Quantifying the level of risk is, however, problematic due to a number of unanswered questions and apparent knowledge gaps. Significantly, included here are:

- A follow-up question requires answering, although it is dependent on the outcome of the first. This question asks if a link to hydraulic fracturing and water contamination is proven, what conditions are associated with these potential impacts? More follow-up questions are likely to emerge should a positive link be proven. Most significantly, it may become crucial that policy makers in regions considering shale gas exploration examine the region's regulatory regime to ensure it is orientated towards minimising these risks. Subsequently, it will be necessary to consider what agency will be tasked to inspect wells and to what standards, and how will shale gas development be monitored, at what frequency, and with whom will monitoring data be shared.

  On the issue of water contamination, the Department for Enterprise, Trade and Investment stated in correspondence with the Committee:

  > *Any proposal to use high volume hydraulic fracturing in oil or gas exploration and production would be assessed by NIEA as part of its regulatory processes. This would consider both the likelihood of pollution occurring (both at the surface and in the sub-surface) and the impact of any such pollution event. Such an assessment would take into account all potential contaminants, whether they were chemical additives to the hydraulic fracturing or drilling fluids, or naturally occurring materials brought to the surface as rock cuttings or in the produced water. It is expected that NIEA will adopt a risk based assessment approach for the protection of groundwater whereby it may restrict or prohibit the use of any substances where they would pose an environmental risk.*[119]

- The issue of water consumption should be considered in the context of local water supplies to determine whether the supply can adequately cope with increased pressure. This consideration is problematic due to the variation in water requirements between wells. Policy makers and developers may seek ways to mitigate water use by recycling waste water. Research and development into alternatives to fresh water (such as salt water and gel based fracturing fluid) might also become a consideration.

[119] Correspondence between Department of Enterprise, Trade and Investment, and Committee for Enterprise, Trade and Investment 06 August 2012

On the issue of water consumption DETI have stated, specifically referencing Tamboran's activities in Co. Fermanagh:

> *Tamboran have proposed that they obtain the water required for hydraulic fracturing from groundwater boreholes with the abstracted water stored ready for use in lined ponds at the well pads. Both the licensing of any proposed abstraction and the monitoring of water abstraction and storage is the responsibility of NIEA.*[120]

- The question of what proportion of waste water returns to the surface remains unresolved. Additional, policy makers and developers should consider how waste water is to be treated and whether there is adequate infrastructure to ensure that it can be treated.

  On the issue of water treatment DETI have stated:

  > *This is a matter for the Department of the Environment which has the regulatory responsibility for the disposal of waste water.*[121]

- Concerns exist around greenhouse gas emissions. The evidence suggests a robust lifecycle analysis of emissions levels remains outstanding. The outcome of such an analysis will enable more certainty as to how shale gas emissions stack up to those of other fossil fuels, including conventional gas. How to deal with fugitive methane emissions is likely to be an issue for policy makers and industry alike, this will likely include consideration of mitigation technology and green completion. DETI has commented on the issue of fugitive emissions:

  > *The Department agrees that there is still some debate over the level of methane emissions associated with shale gas production but notes the introduction of new regulations by the Environmental Protection Agency in the USA, and the ready availability of proven technology, to reduce these emissions.*[122]

- Ensuring well integrity may limit the possibility of water contamination and methane emissions. Policy makers are recommended, by the IEA amongst others, to ensure robust regulations on well design, construction, cementing and testing. On regulation, DETI have stated:

  > *The Regulators Forum will be crucial in bringing together the range of Departments to ensure that the level of risk is assessed and considered centrally and cumulatively. Hydraulic fracturing would only be permitted if the Department can be assured that the appropriate controls and regulations are in place to bring the level of risk to an acceptable level.*[123]

[120] *Ibid*
[121] *Ibid*
[122] *Ibid*
[123] *Ibid*

- Fracture propagation may prove difficult to control, although, it is likely to be in the financial interests of developers to limit propagation. A better understanding of local geology should help to improve methods of fracture control.
- The evidence suggests that hydraulic fracturing has the potential to lead to seismic activity. Developing a greater understanding of geology through surveys is an essential step towards to reducing this risk. To this end, it has been recommended in the literature that the British Geological Survey carry out national surveys. Consideration may be given to the adoption of a traffic light system which may enable early identification of risks and put in place firm procedures to deal with seismicity. Data collection on seismic activity has also been recommended. On seismicity, DETI have stated:

  > *In terms of seismicity, the Department believes that the adoption of appropriate monitoring and mitigation measures, such as those expected from DECC later this year, should ensure that induced seismicity from hydraulic fracturing poses a negligible risk.*[124]

- Shale gas development leads to the consumption of landscape with potential social and environmental implications. A key concern for the House of Commons Committee for Energy and Climate Change was how increased land use could be managed in densely populated areas. This is likely to be less of a concern in Co. Fermanagh where the population density is much closer to that of the US. This, however, is unlikely to negate the need to ensure the social and environmental concerns are addressed.

It should be noted that whilst the granting of petroleum licences and the impact shale gas development might have on the energy mix fall within DETI's remit, a large proportion of the risks associated with development fall within the remit of the Department of the Environment and its associate bodies.

Key aspects arising from the remainder of the paper concern potential resource and the impact on renewable development. On these topics it is worth reiterating the following:

- The European Parliament's report does not appear optimistic with regard to shale gas impact on the European energy mix. They do not, however, rule out positive impacts at regional level. The House of Common's notes that although shale gas might contribute to the UK's energy mix and to security of supply it is unlikely to be a game changer.
- A number of gaps between the US and elsewhere have been identified – e.g. skills and infrastructure – which may hamper the development of available resources. Consideration might be given as to how these gaps may be addressed.

[124] *Ibid*

- Debate exists over the depletion rate of shale gas wells. A robust answer to this is desirable as it is likely to have significant implications on the resource's future role within the energy mix.
- Although, as argued by the UK Government, fossil fuels will continue to play a role in the energy mix, consideration should be given to the signals shale gas development sends to renewable energy markets and the impacts the development of the former might have on the latter.

Consideration might also be given as to how developers and government interact with the public on shale gas development. The evidence surveyed is supportive of transparency and ensuring the public availability of a range of data sources.

The issue of regulation has not been fully addressed in this paper. There is potential scope for an assessment of this area, with a particular focus on the suitability of current Northern Ireland regulations to shale gas development and the identification of areas were further regulation might be required.

6 On-going studies and scope for further research

This final section provides a brief outline of forthcoming reports on shale gas and hydraulic fracture and identifies areas were further work might be considered.

The evidence surveyed identified the following studies which may impact the shale gas debate when published:

- US EPA has also committed to a broader investigation into the *Potential Impact of Hydraulic Fracturing on Drinking Water Resources,* due for publication in draft form in late 2012, with a final peer reviewed publication is expected in 2014
- RoI EPA *comprehensive* study framed by the University of Aberdeen study, due to be commissioned in 2012;
- A number of desktop studies at European Commission level, including studies by the EC Directorate-General for the Environment (on health risks), the EC Directorate-General for Climate Action (gas emissions), and the Directorate-General for Energy (licensing);
- Reviews of regulation are expected by the Environment Agency (EA) in England and Wales and the Northern Ireland Environment Agency is working with the Irish environmental regulator to develop a regulatory framework suitable for cross-border activities;
- The British Geological Survey has begun preliminary work on determining background methane levels in ground water. This work, which includes Northern Ireland, is expected to produce results in March 2013;

- The BGS has also begun work increasing their understanding of UK shales[125]; and,
- The UK Health Protection Agency has established a Working Group of chemical and radiation specialists to collate and review literature, including national and international studies, about the potential health impacts of shale gas extraction.

Some scope for further work has also been identified:

- A full-life cycle analysis of shale gas development to determine its greenhouse gas foot print compared to other energy resources;
- Enhancing the understanding of UK shales, including resource levels, and stresses and faults;
- Monitoring of behaviour of wells after abandonment;
- Further work to define the volume and content of produced water (specific to location);
- The interaction between shale gas development and climate change policy, including renewables;
- Further research and development into shale gas to improve efficiency and enhance environmental protection; and,
- An overview and assessment of Northern Ireland regulations.

[125] Specifically: the depth of potential shale gas reservoirs and location of any overlying aquifers. BGS is also investigating the properties of the intervening rock that will control the movement of water, such as permeability, porosity and fracture density.