
Independent Expert Scientific Panel – Report on Unconventional Oil And Gas

Independent Expert Scientific Panel – Report on Unconventional Oil And Gas

© Crown copyright 2014

You may re-use this information (excluding logos and images) free of charge in any format or medium, under the terms of the Open Government Licence. To view this licence, visit <http://www.nationalarchives.gov.uk/doc/open-government-licence/> or e-mail: psi@nationalarchives.gsi.gov.uk.

Where we have identified any third party copyright information you will need to obtain permission from the copyright holders concerned.

This document is also available from our website at www.scotland.gov.uk.

ISBN: 978-1-78412-683-4

Published by the Scottish Government, July 2014

The Scottish Government
St Andrew's House
Edinburgh
EH1 3DG

List of Acronyms	ii
Acknowledgements	iii
Executive Summary	iv
Chapter 1 - Independent Expert Scientific Panel – Report on Unconventional Oil And Gas	1
Chapter 2 - International context – Economic impact and Geopolitics	5
Chapter 3 - The Current Industry	10
Chapter 4 - The Potential in Scotland	19
Chapter 5 - Technical challenges	27
Chapter 6: The environmental and societal challenges	34
Chapter 7: Regulation and legislative background	52
Chapter 8 - Public awareness and engagement	62
References	71
Appendix 1	85
Appendix 2	89

BAT/BREF	Best Available Techniques/BAT Reference Document
BGS	British Geological Survey
CAR	Water Environment (Controlled Activities) (Scotland) Regulations 2011
CBM	Coal Bed Methane
CCS	Carbon Capture and Storage
CO₂	Carbon dioxide
dB	Decibel
DECC	UK Government Department of Energy and Climate Change
EC/EU	European Commission/European Union
EIA	Environmental Impact Assessment
ERA	Environmental Risk Assessment
GHG	Greenhouse Gas
GNA	Good Neighbour Agreements
HSE	Health and Safety Executive
IBA	Impact Benefits Agreements
IPPC	European Union Integrated Pollution Prevention and Control Directive
kWh	Kilowatt Hour
m³	Cubic metre
MCFD	Million Cubic Feet per Day
MEW	The Management of Extractive Waste (Scotland) 2010 Regulations
M_L	Richter Magnitude (or Local Magnitude) – measure of earthquake magnitude
NGO	Non-Governmental Organisation
NORM	Naturally Occurring Radioactive Material
PAH	Polycyclic Aromatic Hydrocarbons
PEDL	Petroleum Exploration and Development Licence
PM_{2.5}	Particulate Matter up to 2.5 micrometres in diameter
PPC	Pollution Prevention and Control (Scotland) Regulations 2012
PPM	Parts per million
RSA	Radioactive Substances Act 1993
SEPA	Scottish Environment Protection Agency
TCF	Trillion cubic feet (1tcf = 0.028 trillion m ³)
TOC	Total Organic Carbon
UKOOG	UK Onshore Operators Group
VOC	Volatile Organic Compounds

The Expert Scientific Panel wishes to record its thanks and appreciation for the technical advice and support provided by Lin Bunten, Emma Taylor and Ben Jackson of SEPA, and Hugh Barron of the British Geological Survey. Their input was in a personal capacity and does not necessarily reflect the views of their Agencies.

The Panel would also like to extend their gratitude to:

- Dr Colin Ramsay at Health Protection Scotland;
- Martin Birley of Health Impact Associates;
- Ana Maria Esteves from the Community Insights Group; and
- Graham Esson, Team Leader, Sustainability, Policy and Research, Perth and Kinross Council.

1. In September 2013, the Scottish Government convened an Independent Expert Scientific Panel to report on the scientific evidence relating to unconventional oil and gas. The remit of the Panel was to deliver:
 - A robust, well researched evidence base relating to unconventional oil and gas upon which the Scottish Government can reliably base future policy in this area;
 - A well-developed narrative on the environmental and regulatory issues associated with the potential development of unconventional oil & gas in Scotland;
 - An assessment of the potential resources available to Scotland.
2. The remit of the Expert Scientific Panel did not include making recommendations to the Scottish Government. The direction of future policy or potential changes to the regulatory framework is a decision for Scottish Ministers.
3. The following points summarise the key conclusions of the Expert Scientific Panel. These have been arrived at during the Panel's assessment and analysis of the available evidence.

Main Points

- The development of the unconventional oil & gas industry has changed the energy outlook of the United States of America. This has been made possible by technological advances in directional drilling and hydraulic fracturing. The impact of the US shale gas 'revolution' has raised interest in developing unconventional hydrocarbon resources in the rest of the world;
- There could be positive economic impacts from the development of an unconventional oil & gas industry, in terms of jobs created, taxes paid and gross value added. The scale of the impact in Scotland is subject to debate and may only become clear once development is underway. Lack of infrastructure, such as drilling rigs, could have an impact;
- Suitable petrochemical feed-stocks from the North Sea are declining, in particular ethane and other light hydrocarbons. The potential availability of these feed-stocks from unconventional oil and gas resources in Scotland could have a beneficial impact on Scotland's petro-chemical industry in the long term;
- Although further exploratory drilling will be required, Scotland's geology suggests that there could be significant reserves of unconventional oil and gas – the greatest potential reserves are likely to be in the Midland Valley of Scotland;
- When viewed in the context of the factors that have supported coal bed methane and shale gas development in other countries, it seems likely that unconventional gas *could* be developed in Scotland at scale. This is particularly true, given Scotland's domestic oil and gas supply-chain industry, and Scotland's longstanding experience in other extractive industries such as coal mining, shale oil, and conventional oil and gas;

- There are a number of technical challenges associated with unconventional hydrocarbon extraction, though it is the Expert Scientific Panel's view that none of these are insurmountable. The technology exists to allow the safe extraction of such reserves, subject to robust regulation being in place;
- The impact of unconventional oil and gas resources in Scotland on the Scottish Government's commitment to reduce greenhouse gases is not definitive. There could be minimal impact from unconventional hydrocarbons if they are used as a petrochemical feedstock, but lifecycle analysis of an unconventional hydrocarbon industry is required to inform the debate, and provide a clearer view on the impact of their development;
- The regulatory framework is largely in place to control the potential environmental impacts of the production of unconventional oil and gas in Scotland, although there may be gaps to address;
- The high population density of those parts of Scotland most likely to host significant unconventional oil and gas resources would be a challenge for any form of re-industrialisation, and will thus be so for any future unconventional oil and gas industry;
- The development of any new industry is likely to impact society - detecting and alleviating negative impacts, and enhancing positive impacts, is complicated unless careful planning of how to identify impacts is undertaken;
- Public concerns around unconventional oil and gas development include concerns about technical risk such as water contamination, public health and seismicity, but also wider issues such as social impacts on communities, effect on climate targets and trust in operators, regulators and policymakers;
- Many of these social (and environmental) impacts can be mitigated if they are carefully considered at the planning application stage. Added to which, there are already considerable legislative safeguards to ensure such impacts are not realised.
- Early consultation with communities is vital to identify potential impacts on the community, to scope potential benefits and develop plans to mitigate the impacts and enhance the benefits;
- Public engagement is necessary for the development of unconventional oil and gas resources in Scotland and there is a growing body of evidence showing that sustained and meaningful community engagement has beneficial outcomes for communities, operators and policymakers.

Introduction

- 1.1 International interest in the potential exploitation of unconventional oil and gas reserves has increased, largely due to events in the United States over the last decade.
- 1.2 In 2003, it was widely anticipated that the US would be a key destination for future global gas exports. However, it is now anticipated, principally as a result of shale gas production, that by 2015 the United States could surpass Russia as the largest natural gas producer and could become energy self-sufficient in the next 25 years (International Energy Agency, 2012).
- 1.3 Additionally, the chemical industry in the US has undergone a revival due to the availability of cheap feed stocks, such that previously mothballed plants are being brought back into production. It is estimated by the American Chemistry Council that \$100 billion of new chemical plants will be built between now and 2023, creating over 600,000 jobs (American Chemistry Council, 2014).
- 1.4 In September 2013, the Scottish Government convened an Independent Expert Scientific Panel to report on the scientific evidence relating to unconventional oil and gas. The remit of the Panel was to deliver:
 - A robust, well researched evidence base relating to unconventional oil and gas upon which the Scottish Government can reliably base future policy in this area;
 - A well-developed narrative on the environmental and regulatory issues associated with the potential development of unconventional oil & gas in Scotland;
 - An assessment of the potential resources available to Scotland.
- 1.5 On the advice of the Chief Scientific Adviser for Scotland, the Independent Panel has been drawn from experts in the fields of geology, environmental science, engineering and resource extraction to provide a robust, impartial analysis of the available evidence.
- 1.6 All members of the Independent Panel, whose details are given in Appendix A, agreed to serve unpaid in a personal capacity and not as representatives of any particular institution or organisation. The Chair of the Panel is also the Independent Co-Chair of the Scottish Science Advisory Council.
- 1.7 The Expert Scientific Panel recognises that, while there is a significant body of existing, peer-reviewed evidence on unconventional oil & gas, it is a constantly evolving area of research and analysis. Therefore, it is important for readers to note that the Expert Scientific Panel concluded its analysis of the scientific evidence on 30 May 2014¹.

Unconventional Oil and Gas – An Introduction

- 1.8 Conventional oil and gas deposits are contained in porous reservoirs (often limestone or sandstone) that have interconnected spaces. These interconnected spaces give rise to

¹ Data in this report has been updated to take account of the findings from the British Geological Survey's report entitled "*The Carboniferous shales of the Midland Valley of Scotland: geology and resource estimation*", which was published on 30 June 2014 (Monaghan, 2014).

permeability that allows the oil or gas to effectively flow through the reservoir to the well (borehole). The permeable rock is usually trapped below a low permeability layer, and laterally by other low permeability rocks or low permeability faults.

- 1.9 Conversely, unconventional oil or gas deposits, such as shale gas and shale oil, are contained in reservoirs of low permeability, for instance shale rock. In these cases, the oil or gas cannot easily flow through the reservoir, rendering it much more difficult to recover by conventional production techniques.
- 1.10 Coal bed methane (CBM) is also regarded as an unconventional source of gas since, not only is it a low pressure system compared to conventional gas but also the gas, rather than being held in pore spaces, is adsorbed onto the coal.
- 1.11 The existence of unconventional resources has been known for many years. In the last decade a combination of economic and geopolitical factors, together with advances in directional drilling and well stimulation technology, has rendered them commercially recoverable on a large scale.

Economic and Geopolitical Factors

- 1.12 The last 20 years have seen a more than 20-fold increase in the price of crude oil, together with similar increases in the price of natural gas. This has led companies to focus on developing reserves that would formerly have been judged to be uneconomic. Furthermore, changes in the political landscape have focused attention on developing reserves in areas of the world judged to be more politically stable.

Technological Advances

- 1.13 In terms of technological advances, the two key drivers have been directional drilling and hydraulic fracturing, commonly referred to as 'fracking'. Neither of these technologies are new, in that both have been used in the oil industry for the last fifty years. There has however, as with many technologies, been considerable advancement in the last few years.
- 1.14 Directional drilling is the ability to deviate the drill head from the vertical in a controlled manner, such that different areas of an actual or potential reservoir can be accessed from a single position on the surface. This innovation has been important in exploiting off-shore reserves, particularly in deeper waters of the North Sea for instance, where the costs of locating a drilling rig or establishing a production platform can be high. In many of the currently producing fields in the North Sea, wells drilled from a single platform will extend out under the sea bed for up to 5 km. Furthermore, at Wytch Farm in Dorset, discovered in 1973 and one of the largest onshore oilfields in Western Europe, directional drilling from on land has allowed oil to be recovered from some 10 km beyond the coastline.
- 1.15 In producing hydrocarbons from unconventional shale or coal bed methane reserves it is usual to drill a number of horizontal wells through the reservoir. In the case of coal, the natural fractures of the coal are often sufficient to enable gas flow. In the case of shale gas and oil, hydraulic fracturing techniques have to be used to achieve production.

1.16 Hydraulic fracturing involves fracturing the reservoir rock in order to increase its permeability. This is generally achieved by injecting fluid into the well at high pressure to create and propagate fractures a designed distance into the surrounding reservoir rock formation. In shale, the injected fracturing fluid is mainly water (ca. 95%) containing small quantities of sand or similar particulate matter, referred to as the proppant, to prop open the fractures. Small quantities of other additives may also be used to keep the proppant in suspension and increase the lubricating properties of the fluid.

1.17 The fractures created by the technique may only be a few micrometres in width and are usually limited in length to a few tens of metres. Technical advances, particularly over the last decade, have allowed the extent of the fractures to be more accurately predicted, controlled, and remotely monitored using micro-seismic techniques, thus increasing the accuracy and effectiveness of the technique.

1.18 All of the above issues are covered in more depth in the body of the report.

The Report

1.19 In this report, the Expert Scientific Panel has attempted to address the issues relevant to the impact of the development of unconventional oil and gas resources in Scotland. These include:

- the potential magnitude of unconventional oil and gas resources in Scotland and their commercial potential;
- consideration of the global status of unconventional gas exploitation and whether the technology exists to allow unconventional gas resources to be extracted safely;
- the key environmental, public perception, and public health challenges surrounding the exploitation of unconventional hydrocarbon resources;
- whether the current regulatory framework is adequate to cope with the development of unconventional oil and gas reserves;
- how the potential development of unconventional oil and gas resources in Scotland would sit with the Scottish Government's commitment to reduce greenhouse gas emissions;
- how to successfully and constructively engage with communities and environmental groups in a meaningful and fact-based debate on the merits or otherwise of the development of unconventional oil and gas resources.

1.20 In addressing these questions, the Panel has not only relied on the knowledge and expertise of the individuals comprising the group (Appendix 1), but has also received presentations from third parties, including industry representatives, planning authorities, economic experts and non-governmental organisations (NGOs) (Appendix 2).

1.21 The Panel has sought, as far as possible, to rely on independently verified data or peer reviewed publications. Wherever possible, peer-reviewed references from academic literature have been used. Several of these have been 'in press' versions that have gone through peer review but which have not yet been published. Overarching reports from academic bodies, such as the Royal Society and the Royal Academy of Engineering, that have been subject to peer review, have also been used, as have reports from geological

surveys, such as the British Geological Survey and the Polish Geological Institute. Reports from NGOs or lobby groups have not generally been cited in the text, although these have often provided useful links to peer-reviewed papers and research. Statistics from Government publications and reports have also been cited, which are not typically peer reviewed. On rare occasions, links to newspapers or television articles and blogs have been cited if they are the only factual evidence available (for instance, citing a given policymaker or for an industry view on insurance risk).

- 1.22 Throughout the report, the Panel has sought, where possible, to set numbers in context. This is not to seek to either minimise or maximise the apparent risks or benefits, but rather to seek to place large and/or unfamiliar numbers into context for readers unfamiliar with science or engineering.

Introduction

- 2.1 The emergence of unconventional oil & gas as a commercially-available fossil fuel source has had a dramatic impact on the global energy system. The effects of relatively cheap shale gas availability in the United States has had knock-on effects globally, which have also been felt in Scotland.
- 2.2 In this chapter, the Expert Scientific Panel has reviewed the evidence on the global impact of unconventional hydrocarbons and looked at the potential level of global and national resources. The Panel has also considered what the development of an unconventional oil & gas industry could mean for Scotland from an economic perspective.

The United States

- 2.3 In 2003, the Energy Information Administration (EIA) forecast that United States gas imports would more than double, increasing from 104.8 billion m³ (3.7 trillion cubic feet - tcf) in 2001 to 220.9 billion m³ (7.8 tcf) in 2025. It was widely anticipated that the US would be a primary destination for future global natural gas exports.
- 2.4 However, by 2012, dry shale gas production rose to 271.8 billion m³ (9.6 tcf) from 8.5 billion m³ (0.3 tcf) in 2000 (US Energy Information Administration Outlook and Analysis Report 2013) – making up 40% of US dry natural gas production; and the share of imports in US natural gas consumption dropped from 16.5% in 2007 to 11% in 2010 (Dreyer, 2011). “Dry” in this sense means methane gas without additional hydrocarbons that contain more carbon atoms in their molecules.
- 2.5 The EIA commented in its 2013 Analysis and Projections report that there are 18.04 trillion m³ (637 tcf) technically recoverable dry shale gas resources, including proven reserves of 2.66 trillion m³ (94 tcf) of shale gas. This compares to a 2012 production rate of 736 billion m³ per year (26 tcf per year). Given that there is potentially much more commercially available resource to be recovered, it is unlikely unconventional gas is a short-term phenomenon for the USA.
- 2.6 The International Energy Agency (IEA, 2012) expects that the US will surpass Russia as the world’s largest natural gas producer in 2015, and become a net gas exporter by 2020. It also estimated that the US will be able to produce enough energy resources to fulfil its domestic requirements in 25 years.

Drivers and Impact

- 2.7 There are several factors which have supported the development of unconventional oil and gas production in the US.
- 2.8 Principal among these are a perceived lenient regulatory regime, and a resource ownership structure which enables swift decision making. Moreover, the US has developed technological expertise over many decades through its onshore oil and gas industry in the techniques of horizontal drilling and hydraulic fracturing which are particularly important in

the exploitation of unconventional oil and gas reserves. This places the US with competitive advantages that have supported the rapid development of the industry.

- 2.9 A key result of the US shale industry has been to effect a change in the US energy mix. There has been an acceleration in the long-term trend of gas and, to a lesser extent, renewable energy replacing oil and coal in power generation; added to which the increased availability of domestic gas has led to a significant drop in domestic gas prices. The share of natural gas in total US primary energy consumption reached 26% in 2011, rising from 23% in 2007 (Dreyer, 2011).
- 2.10 In 2010, prices were less than \$5.00 per million British thermal units (MMBTU) for the second consecutive year despite the fact that in 2010 gas consumption, at 682.4 billion m³ (24.1 tcf), was at a historic high (Stevens, 2012). Analysis from the International Gas Union (2013) indicates that the 2012 wholesale gas price was close to \$10 per MMBTU in the UK, compared to just over \$2 per MMBTU in the US.
- 2.11 Another key effect has been a consistent reduction in US energy-related CO₂ emissions over the last few years which has been predominantly due to the increased use of shale gas instead of coal in power generation. According to US EIA statistics, the US achieved a reduced level of CO₂ emissions in 2012 (5.29 billion tonnes), similar to that in 1995 (5.32 billion tonnes), which represented a 3.8% reduction on the 2011 figures and 12% less than the 2007 peak. It is noteworthy that this also coincided with a 2.8% increase in US GDP (US Department of Commerce Bureau of Economic Statistics, 2013).
- 2.12 The increase in the production of shale gas and liquids has also had a major impact on the downstream activities of the chemical industry. The American Chemistry Council announced in February 2014 that potential U.S. chemical industry investment linked to natural gas and natural gas liquids from shale formations had topped \$100 billion. It was noted that this could lead to \$81 billion per year in new chemical industry output and 637,000 permanent new jobs by 2023, with more than half of the investment by firms based outside the United States.
- 2.13 The impact can also be seen in the development and use of infrastructure. For example, Liquefied Natural Gas (LNG) facilities which were being built before the shale industry development to allow the import of gas are now being developed into platforms that can allow the US to export gas for the first time. The most likely export market will be Asia (particularly China, Japan and Korea), where the demand for gas imports increased almost 500% between 2000 and 2011 and is expected to continue upwards (Dreyer, 2012).
- 2.14 Although there have been positive impacts in the US – stimulating the economy, reducing CO₂ emissions, reducing consumer bills – the knock-on effects are felt globally. One example is the sudden lack of competitiveness from European petrochemical plants – where feedstock prices can now be double those of rival plants making identical products in the US. Consequently, if this trend continues, the environment in which these plants operate will be challenging unless low-cost imports can be achieved, or low-cost domestic production of ethane and naphtha can be substituted for established higher cost North Sea sources.
- 2.15 Lower coal consumption in the US has led to an excess supply on the global market. This has resulted in less demand for more expensive coal produced in the UK, for example, and

contributed to company failures in the Scottish opencast mining sector in 2013. Cheaper coal is being used increasingly for electricity production, particularly in China and India. Consequently, the displacement of coal by cheaper shale gas in the US may not necessarily lead to a global reduction in greenhouse gases such as CO₂.

Continental Europe and the rest of the world

2.16 Estimates from 2011 (US EIA, 2011) suggest that technically recoverable shale gas could increase total global gas resources by 40%. Outside the US, the largest estimated technically-recoverable shale gas resources are thought to be in China (31.6 trillion m³ - 1,115 tcf), Argentina (22.7 trillion m³ - 802 tcf), and Algeria (20 trillion m³ - 707 tcf) (US Energy Information Administration, 2013).

2.17 China is now the world's biggest CO₂ emitter and is heavily reliant on energy imports. To help address this, they are actively trying to develop their unconventional gas reserves, with the aim of increasing the share of natural gas in the country's energy consumption to 8% by 2016. However, China faces significant hurdles in developing their unconventional reserves due to geological, infrastructure and water supply issues. China has also recently signed a 30 year, \$400 billion dollar supply contract for natural gas from Russia (BBC News, 2014) - this may also have a strategic impact on the degree to which China will develop indigenous unconventional hydrocarbons.

2.18 In continental Europe, the largest estimated (unproven) technically recoverable shale gas resources are in Poland (4.2 trillion m³ - 148 tcf), France (3.9 trillion m³ - 137 tcf), Romania (1.4 trillion m³ - 51 tcf), Russia (8.1 trillion m³ - 287 tcf) and Ukraine (3.6 trillion m³ - 128 tcf) (US Energy Information Administration, 2013).

2.19 While it may prove more difficult to replicate the unconventional gas boom witnessed in the US, there could be significant drivers for its development in Europe.

2.20 In some parts of Europe, there has been a traditional and enduring dependence on gas imports from Russia. Therefore, access to domestic sources of gas could help to increase energy security in European countries and reduce risks around security of supply.

The United Kingdom and Scotland

2.21 The development of unconventional oil & gas in the United Kingdom and Scotland is at a very early stage. However, the British Geological Survey has recently published resource-in-place estimates for shale gas and shale oil (but not CBM) in the Midland Valley. It is estimated that there could be between 1.4 and 3.81 trillion m³ (49.4 – 134.6 trillion cubic feet) of shale gas and between 3.2 and 11.2 billion barrels of shale oil in the Midland Valley study area (Monaghan, 2014). Further details can be found in Chapter 4.

2.22 There are diverging views on the impact of unconventional hydrocarbons in the UK and Scottish context.

2.23 The UK Government is supporting the development of the shale gas industry with the aim of delivering a reduction in domestic prices; a corresponding increase in security of supply; and providing economic growth and jobs. In order to enable this, the UK government announced fiscal incentives with a view to stimulating commercial investment.

These incentives include refunds of business rates, payments to affected communities, and low tax rates on hydrocarbon production.

2.24 It is also clear that, to achieve the success seen in the USA, four factors would need to coincide in the UK:

- (i) the ability to overcome public concerns;
- (ii) a variety of operators – to identify the most effective and efficient methods to develop UK shales;
- (iii) a skilled workforce and an effective supply chain to enable low cost drilling;
- (iv) rapid, expert, and rigorous licensing and regulation.

It is far from clear whether any such coincidence could occur here.

2.25 Moreover, some commentators believe that the interconnectedness of the gas market in Europe means that the benefits to the UK economy from unconventional gas production in the UK will be limited. The main rationale for this belief is the likelihood that any such production would enter the European wide market under normal procedures and consequently any national impact on prices and supplies would be marginal. Analysis by Bloomberg also suggests that the UK, as a net importer of gas, would be able to absorb up to 113 million m³ per day (4 billion cubic feet per day) of natural gas into the market without altering the fundamental dynamics. The figure of 113 million m³ per day (4 billion cubic feet per day) is the highest figure for UK shale gas production under Bloomberg's most optimistic scenario (Bloomberg New Energy Finance, 2013).

2.26 Despite the uncertainty surrounding the potential impact on supply and price, there could be other positive benefits flowing from the development of indigenous unconventional oil and gas reserves in Scotland. This could be particularly so in respect of the petro-chemical industry, which is a significant component of the Scottish economy.

2.27 Suitable petrochemical feed-stocks from the North Sea are declining, particularly ethane and other light hydrocarbons. The price of feedstock is typically 50 - 80% of most products. Consequently, petrochemical plants are looking to develop facilities to allow them to achieve low-cost import of such feed-stocks, such as are obtained from unconventional oil and gas reserves from the US.

2.28 The Grangemouth plant is one of only four gas crackers in Europe which can use ethane gas to manufacture ethylene. Consequently, the operators are constructing an import terminal capable of receiving ethane from imported US shale gas during the next 15 years. This will enable the ethylene cracker at Grangemouth to increase its throughput from less than half of its capacity today, to 100%. Ineos plan a similar project at its smaller Rafnes facility in Norway, allowing it to bring in ethane gas from the US from 2015.

2.29 The Grangemouth refinery, which is connected to both the Forties oil pipeline from the North Sea, and by a 93km pipe, to the Finnart oil terminal on Loch Long (which can receive deepwater oil tankers of 324,000 tonnes), has the capacity to process 210,000 barrels (33,000 m³) of crude oil per day and to produce around 9 million litres of fuels per day – including ultra-low sulphur (ULS) diesel and ULS petrol. The Ineos chemical plant can produce 1 million tonnes of petrochemicals per annum. The ability to potentially source

these products from the production of Scottish hydrocarbons could place Scottish plants at an advantage in an increasingly competitive world market.

The Potential Economic Impact of Unconventional Gas Development

- 2.30 As noted earlier, the development of unconventional oil & gas is at a very early stage in Scotland and the UK – therefore, any analysis of economic impact will be subject to a great degree of uncertainty. For example, the economically recoverable reserves will be largely unknown until further test drilling is undertaken. Equally, there is no readily available information on the potential economic impact of unconventional oil production in Scotland or the UK. Much of what is available only relates to unconventional gas, and shale gas in particular.
- 2.31 The cost of extracting unconventional hydrocarbons will ultimately determine whether it will be economic to do so and analysis by Bloomberg suggest the experience of low cost extraction in the US is unlikely to be repeated in the UK. It cites the main reasons as being differences in geology, ownership of land rights, lack of a drilling services market (noting that the vast majority of required equipment is currently in North America) and lack of midstream infrastructure (such as connecting pipelines and gas processing equipment, which is capital intensive) (Bloomberg New Energy Finance, 2013).
- 2.32 The analytical uncertainty is shown in available figures for potential economic and employment impacts of commercial scale unconventional gas industries operating in the UK. A report from the Institute of Directors (IoD) suggested that a multi-year development of 100 shale gas pads with 40 lateral wells could result in a peak capital and operating expenditure of £3.7 billion, supporting up to 74,000 direct, indirect and induced jobs (Lewis and Taylor, 2013).
- 2.33 Based on this high case scenario outlined by the IoD report, a subsequent industry report commissioned by the UK Onshore Operators Group (UKOOG) on supply chain and skills requirements indicated that the industry may need to spend up to £33 billion in supply chain activities, to realise the vision of 4,000 lateral (horizontal) wells over an 18 year timeframe (2016 - 2034). Interestingly, this report noted the potential for up to 64,500 direct, indirect and induced jobs at peak (Ernst & Young, 2014).
- 2.34 Both of these reports vary significantly from the jobs estimate in the Strategic Environmental Assessment written by AMEC for the UK Government. Under a high case scenario of industrial development, it is noted that between 16,000 and 32,000 full-time equivalent jobs could be created. However, caution is required in comparing the two figures, due to differences in methodology and industry development scenarios (DECC, 2013).

Coal Bed Methane

A brief history of coal bed methane developments worldwide

- 3.1. Methane associated with coal-bearing strata was initially encountered and dealt with as a safety hazard in active coal mines. Some of the earliest historical accounts of 'firedamp', which is the flammable mixture of methane and air found in many mines, were in Scottish coalfields.
- 3.2. Although Scottish coal-bearing strata would not generally be considered "gassy" by later UK and global standards (DECC 2010), methane was certainly present in sufficient abundance to give rise to explosions. In many cases, there was loss of life, such as at High Blantyre in 1877 (207 killed) and Udston (Hamilton) in 1887 (73 killed) (NCB, 1958).
- 3.3. As safety standards in Scotland's collieries improved, active methane drainage schemes became commonplace (NCB, 1958). Indeed, several large collieries installed methane capture and use systems, providing some of the power needed to operate mining machinery.
- 3.4. These experiences, accompanied by those in conventional oil and gas operations offshore, resulted in widespread acknowledgment of how methane can be handled safely, and the conversion of UK domestic gas supplies to North Sea gas in the 1970s provided further familiarity.
- 3.5. Scotland was an early entrant into the exploitation of gas from active mines. For instance, at Cardowan Colliery, the Dumbreck Cloven seam had 3.6 m³/tonne gas, and the Kilsyth coking seam 4.9 m³/tonne gas, which was sold commercially from 1972 - 1982. Despite early involvement, Scotland has not participated in the 'abandoned mine methane' industry. This industry is well developed in the coalfields of the English Midlands by Alkane Energy plc for instance (DTI, 2001; Jardine *et al.*, 2009).
- 3.6. Commercial interests in Scotland's potential coal bed methane (CBM) industry are currently small. This can partly be attributed to the availability of abundant North Sea gas over the last three decades. It is important to note that CBM involves only the extraction of pre-existing methane from coal seams. It *does not* involve conversion of the coal itself into methane.
- 3.7. Large-scale implementation of CBM was pioneered in the USA. It was originally developed as a form of advance methane drainage prior to deep mining in the Black Warrior Coal Basin, Alabama, in the 1970s. Together with the laterally equivalent North Appalachia Basin; the Powder River Basin in Wyoming; and the San Juan Basin in Colorado, these now account for more than half of the 2.8 trillion m³ (100 tcf) of recoverable CBM resources in the USA (Halliburton 2009).
- 3.8. Although recoverable CBM resources in the world are not well characterised, it is conservatively estimated that global CBM resources amount to at least 33.98 trillion m³ (1,200 tcf), with particularly substantial resources in Canada, Russia, China and Australia (Sloss, 2005).

3.9. CBM extraction is achieved using boreholes drilled from surface, as follows:

- (i) Identify target coal seams using geological exploration methods and previous borehole, gas and oil production, information, typical to the industry;
- (ii) Drill two or more boreholes into the target seam, and a few metres below to create 'sumps' beneath the seam floor level. These boreholes should be thoroughly sealed-off (by means of steel casing cemented into place) from the strata overlying the coal seam: only the target coal seam is open to the borehole. Several of these bores are likely to be deviated, to run horizontally along the coal seams, in order to carry maximum gas to the vertical production borehole;
- (iii) Install pumps with very high lift capabilities into the borehole sumps;
- (iv) Pump the boreholes to de-pressurise groundwater in the coal seam until the head of water (height of water column supported by pressure at the base of the borehole) in the borehole drops below the threshold that allows mobilisation of desorbed gas into it. Unlike in many conventional oil and gas reservoirs (where the gas will be at a sufficiently high pressure to bubble through a much larger head of water in the borehole) in CBM fields pumping usually has to be maintained until the water level has dropped below the seam floor level before the bulk of the methane will enter the borehole. This is the reason why overlying strata are thoroughly cased-out in CBM operations, as otherwise more groundwater than necessary would need to be pumped from great depth. Gas initially moves from microscopic pores in the coal, and subsequently degasses from dissolution in the groundwater. Gas travels to the borehole along the face cleat (dominant fractures in the coal). Thus, when deviated horizontal boreholes are used, these are oriented to run perpendicular to the face cleat, thereby encouraging maximum flow of gas into the borehole;
- (v) Collect the gas moving into to the boreholes and dispatch it to surface facilities for processing and use;
- (vi) Dispose of the pumped water (production water), either to sewer or surface water (following any required treatment) or by reinjection.

3.10. These steps are common to all CBM operations. In many cases, the native permeability of the coal seam will prove to be too low, and either or both of the following 'stimulation' techniques may also be applied:

- (i) Direct borehole linking, by means of within-seam directional drilling, which ensures far more of the natural small cracks in the coal are exposed to the borehole wall;
- (ii) Hydraulic (or other) fracturing of the coal seam to increase permeable flow.

3.11. While a simple fracturing process to increase permeability was carried out on vertical boreholes during early exploration of CBM in Airth in the mid-1990s (see 3.14 for more detail), none of the coals appraised for commercial-scale CBM in Scotland to date should require hydraulic fracturing of the horizontal borehole. This is due to their distinctive physical properties compared to those found in other continents.

3.12. In recent years, several mature CBM fields in other continents have been subjected to injection of CO₂, which has routinely been used as an agent to increase production from mature oil wells (so called CO₂-enhanced oil recovery). In CBM production, injected CO₂ preferentially binds to coal surfaces and actively displaces residual methane to the

production boreholes. This approach has been applied with considerable success in the Bowen Basin in Australia for instance (e.g. Golding *et al.* 2011) and is referred to as enhanced coalbed methane recovery (ECBM) (DTI 2001).

Recent and current CBM activity in Scotland

3.13. To date, preliminary investigations have been undertaken at five locations in Scotland (summarised in Table 3.1). However, only two CBM fields have been explored in any detail, and only one has proceeded to pilot testing for gas production.

Table 3.1 – Summary of Coalbed Methane Site Investigations in Scotland, 1993 - 2014

Licence (PEDL) no.	Site	Company	Comments
133	Airth	Composite Energy / Dart Energy	15 boreholes have been drilled and some pilot gas production successfully achieved. For further detail see Section 3.14 below.
159	Canonbie	Greenpark / Dart Energy	8 boreholes have been drilled, but no gas production has yet been undertaken. For further detail see Section 3.15 below.
161	East Fife	Composite Energy / Dart Energy	A single exploration well was drilled by Composite Energy prior to their acquisition by Dart Energy in 2012. 10km of seismic line data are being assessed together with the well data before any further proposals are made.
162	Lanarkshire	Reach Coal Seam Gas	An initial proposal to drill near Moodiesburn was withdrawn in early 2012 after more than 200 objections were lodged. The company has planning permission for a gas exploration and production facility to extract coalbed methane at Deerdykes, Cumbernauld. A CAR authorisation for the construction of one investigatory borehole at the Deerdykes site has been issued by SEPA.
163	West Fife	Composite Energy / Dart Energy	A single exploration well was drilled by Composite Energy prior to their acquisition by Dart Energy in 2012. 10km of seismic line data are being assessed together with the well data before any further proposals are made.

3.14. *Composite Energy / Dart, Airth PEDL 133 – Historical analysis*

- Exploration initiated by Hillfarm Coal Company in 1993;
- Assessment of old records showed that the methane content in the Cloven and Kilsyth seams at Cardowan Colliery varied between 3.6 - 4.9 m³/tonne (Bacon 1995). Other National Coal Board data had indicated low gas contents in the overlying Upper Limestone Group and Coal Measures (Creedy 1991);
- The first well was drilled at Airth (No 1) and accessed the Bannockburn seams, which proved to have high methane contents (8-10 m³/tonne) and a fracturing process increased the permeability to 25 millidarcy (mD);
- Gas production from Airth No 1 began at 1.7 million m³/day (60 million cubic feet per day - mcf) in January 1994, later declining to 170,000 m³/day (6 mcf), and rose again to 0.99 million m³/day (35 mcf) in 1995 (Bacon 1995). Water co-production rates initially reached 42.5 m³/day (260 barrels per day), declining to 4.9 m³/day (30 barrels per day) by 1995 during gas production (Bacon 1995);
- Coalbed Methane Ltd took over the PEDL by 1996, and drilled Airth 2, 3 and 4 wells – their gas production rates are unknown, but a water production rate of 8m³/day (50 barrels per day) was noted in 2001;
- Composite Energy had taken over Coalbed Methane's interests by 2004, drilling Airth boreholes 5 to 11 by 2007, with horizontal completions;
- Dart Energy acquired the PEDL in 2011, by which time a total of 15 wells had been drilled, with small scale gas production;
- In August 2012, Dart Energy submitted its planning application for the Airth coal bed methane development to Falkirk and Stirling Councils. The application went to planning inquiry during March 2014. The outcome is unknown at the time of writing.

3.15. *Greenpark/Dart Energy, Canonbie PEDL 159 – Historical analysis*

- The coalfield within the PEDL 159 area was known to have high gas contents from ten boreholes drilled between 1955 and 1983 by the National Coal Board (later British Coal). Records for these boreholes are held by BGS;
- A large subsurface area, between the Scottish and Cumbrian outcrop areas of the coalfield has never been mined;
- Greenpark-Marathon conducted exploration at the site, drilling 8 wells before April 2012. 18 additional borehole sites are already permitted;
- Two of the former Greenpark licences issued by SEPA allowed for "the injection of fracking fluids into groundwater" in coal seams at Mouldyheads and Broadmeadows, using laterals drilled into 5 individual seams. The plan was to use nitrogen foam frack (70% by volume nitrogen gas) rather than water, at an operating pressure of 17 MPa at depths between 560 and 1020 metres below ground, with microseismic monitoring to check no fracture propagation reached overlying aquifers. These fracking operations were never implemented;
- Dart Energy Ltd acquired the licences in 2012 and are proposing development without fracking, along the same lines as their Airth operations.

Economics of CBM nationally and internationally

- 3.16. The economics of CBM do not differ notably from those of any other source of natural gas. The market price for gas, weighed against the costs of exploration, development and

production, determine whether and when a given CBM prospect becomes economically viable. To date, natural gas prices have not been subject to global trading in the way that oil is, mainly due to the costs of inter-continental transport (e.g. in tankers as LNG).

- 3.17. Therefore, natural gas continues to be traded in regional markets with distinct prices. It has been suggested that this system may soon break down, if the projected scale of the 'shale gas revolution' in the USA is realised over the next decade or so, with large-scale LNG exports from the USA across the Pacific and Atlantic oceans. However, this is still subject to much debate (Rogers, 2011; Martin, 2013).
- 3.18. The development of the US shale gas industry is depressing the price of coal (which is globally traded) as US producers export coal at very low prices. This means that substantial Scottish coal reserves that were considered to be reasonable prospects for new opencast (or even deep mine) developments as recently as the first quarter of 2013 are now rendered uneconomic. The identical effect in April 2014 is also forcing closure of the remaining English coal mines. The effect is that – ignoring emissions or environmental costs – coal has become a low cost fuel, whereas gas in the UK has increased in price to become the higher cost fuel.
- 3.19. However, factoring in emissions and environmental costs, the use of coal for electricity generation should become less attractive as a result of UK regulations that require new coal plant to be fitted with CCS technology. Conversely, gas is preferred by a UK Treasury policy that new gas plant need not fit CCS, and is less penalised by a carbon base price in the UK electricity market.
- 3.20. The overall effect is that UK shale gas will not be exploited unless it is cheaper than imported gas. Further, it is unlikely to be exploited until the use of cheap imported coal is curtailed through enforcement of existing requirements that coal-fired power plants have their emissions abated in future by means of carbon capture and storage. This may have the effect of making coal-fired electricity generation relatively more expensive than using gas for electricity production.

Shale Gas and Shale Oil

A brief history of shale gas and shale oil worldwide

- 3.21. The world's first industrial-scale hydrocarbons industry was in Scotland, exploiting organic-rich shales which are now regarded as desirable shale gas prospects. Organic material is present in sedimentary rocks that, when heated naturally in the Earth's crust, breaks down into petroleum and natural gas. The historic industry in Scotland involved conventional mining of the shales, with any trapped gas being vented to the atmosphere, and subsequent retorting of the run-of-mine product to derive paraffins and related liquid hydrocarbons (Carruthers *et al.* 1927; McKay, 2012), with the burnt waste rock being tipped to form the distinctive pink bings of West Lothian.
- 3.22. There does not seem to be any realistic scenario for a resumption of oil production from Scottish oil shales by the historic methods of mining and retorting the shales at surface. The mined rock masses themselves are no longer shale gas prospects either. This is because the mining left behind networks of highly interconnected and largely flooded old mine workings, which long since de-gassed the uppermost few hundred metres of the shale

sequences they penetrated. It is therefore more likely that unmined portions of these horizons deeper underground could be targeted for future shale gas development: there would be no incentive to explore for shale gas in close proximity to old mine workings.

3.23. Scotland has had very little onshore conventional hydrocarbon production. The first gas discovery in Scotland was British Petroleum's borehole in the Salsburgh anticline in 1944, which reportedly flowed at 934 m³/day (33,000 cubic feet/day) from the Strathclyde Group (which is now encompassed within PEDL 162). The commercial field at Cousland operated from 1957 - 1965 and a gas well was completed at Bargeddie in 1989, reportedly flowing at 11,327 m³/day (0.4 million cubic feet/day) of gas – however, this field was not developed.

Technology used currently

3.24. The exploitation procedure for shale gas differs from that of CBM. It is probable that Scottish geology hosts several different types of shale containing gas (further discussed in Chapter 4). Additionally, Scotland certainly hosts a type of shale which can produce oil directly. Although widespread globally (World Energy Council 2010), oil shale deposits similar to those in Scotland have not yet been widely exploited by drilling, but by mining. The exception to this is the oil shales of the eastern Baltic States, though exploitation of those deposits declined markedly following the transition to a market economy. The much-discussed Athabaskan tar sands of Canada are geologically dissimilar to Scottish oil shales.

3.25. Shale strata similar (although not identical) to the Lothian oil shales are increasingly being exploited as shale gas prospects by means of boreholes drilled from surface. This is the approach taken in many parts of North America, and prospects for similar activity are increasing elsewhere.

3.26. In summary, the shale gas or shale oil exploitation process is as follows:

- (i) Identify target shale sequences using conventional geological exploration methods;
- (ii) Drill boreholes into the target sequence, carefully installing hollow steel casing to support the borehole, and to prevent contamination of shallower porous aquifers by drilling or formations waters, or gas produced from depth. The casing must have a gas-tight bond by cementing to the surrounding rock casing and cementing them out above the target sequence;
- (iii) Undertake hydraulic fracturing (fracking), using batteries of pumps at surface, inject water (with around 5% of additives, being mainly sand grains) at pressures carefully calculated to overcome the yield strength of the shales, so that they either open up pre-existing fractures or create new ones. Additives are typically 5% sand "proppant", to physically keep the fractures open, and 0.1 - 0.2% chemicals to enhance water flow and inhibit unwanted bacterial growth;
- (iv) Pump the injected water plus any admixed native groundwater (likely to be scarce in shales; Younger 2007) back to surface, until such time as the level of water in the borehole drops below the threshold that allows gas to overcome the water pressure and move from the pores of the shale into the borehole;
- (v) Collect the gas or oil moving to the boreholes and dispatch it to surface facilities for processing and use;
- (vi) Dispose of the pumped water, either to sewer or surface watercourses (following any required treatment), or else by reinjection to the subsurface.

- 3.27. To ensure continued gas production, steps (iii) through (vi) may need to be repeated over the years, until all the economically recoverable gas has been extracted. In principle, injection of CO₂ could help displace further methane into the production boreholes (in a manner similar to ECBM), though this requires specific borehole layouts and proximities that are less common in shale gas operations than they are in CBM.
- 3.28. Some - but by no means all - shale gas operations also yield appreciable quantities of oil. It is not yet clear whether any such possibility of shale *oil* production exists in Scotland.

Economics of shale gas nationally and internationally

- 3.29. The principles of CBM economics apply equally here: gas or oil produced from shale using the above approach must compete in the respective regional (gas) and global (oil) markets. The market costs of these commodities will determine whether the costs of exploration, development and production are justifiable.
- 3.30. As Scotland has very little onshore hydrocarbon exploration and development activity, drilling costs will be higher compared to North America, but could decrease if a larger market encouraged companies to make more equipment and labour available. However, if the postulated globalisation of gas markets does occur (Rogers, 2011; Martin, 2013), it may well result in Scottish deposits being left undeveloped for the foreseeable future, as existing production costs would likely remain uncompetitive internationally.
- 3.31. The impact of US shale gas on the price of coal (which is globally traded) is now being felt in Europe (Rogers 2011). This does not necessarily mean that less coal will be used however, as cheap imports simply displace locally produced coal. Low prices could also increase the use of coal over other types of energy resource.

Challenges for Scotland

- 3.32. Most of Scotland's onshore coal bed methane and shale gas resources occur in and around the former coalfields and oil shale fields, which remain amongst the most densely-populated parts of the country. Any industrial development in a densely-populated area will face significant challenges, and unconventional gas will be no exception to this. Exploration and development of gas shales in North-East Scotland or in the Inner Hebrides would be in sparsely populated regions – where local employment opportunities during shale gas operations could mean different public attitudes. It is possibly helpful to identify what is technically different or distinctive about shale gas drilling, compared to routinely accepted types of onshore drilling.
- 3.33. Contentious issues are likely to include truck movements, temporary visual impact during drilling and any other issues typically arising due to proximity of long-term plant to other properties. These issues apply to many other industrial developments, of course. Truck movements could be minimised where water supply can be obtained from the public water mains, or by a licensed abstraction from a nearby waterbody.
- 3.34. It is increasingly common practice in the US for shale gas pads to host multiple wells (National Petroleum Council, 2011). Multiple well heads are spaced a few meters apart on a single well pad. In addition each well could have multiple or stacked "laterals". Laterals are subhorizontal wells deviated from the main wellbore in multiple directions at the same

level. Stacked horizontal wells target rock formations at different depths, either because the unit is very thick, or because there are multiple, stacked target horizons. This kind of multi-well, multi-lateral pad accesses a larger volume of rock for a roughly equivalent surface footprint (and reduced cost) (Husain, *et al.* 2011).

- 3.35. There has been public concern about the number of wells required to access UK unconventional gas resources, given that the UK has a much higher population density than much of the USA. Because multi-well, multi-lateral pads service a larger volume of rock, they will require larger volumes of water and other supplies to be delivered and wastes to be shipped out of a single pad. Higher volumes could result in significant economies of scale that may address some of the public's concerns. For instance, the point at which it becomes more economical to develop a water pipeline rather than to have water delivered by truck is dependent on the volume of water. Multi-well, multi-lateral pads may encourage the use of water pipelines over tanker delivery, with the benefit of reducing the risk of road traffic accidents and the visual, noise and pollution disturbance of truck traffic.
- 3.36. Noise is frequently mentioned as a potential impact. However, modern deep drilling in the UK produces little external noise, and that noise is specifically regulated and enforced by planning consents. Acoustic insulation technology has long since been developed to ensure noise levels from drilling comply with strict limits imposed by planning authorities. On modern drilling rigs, even rig-hands do not need to wear ear protection. Recent experiences in northern England (Younger 2013) of deep geothermal drilling using rigs previously used for CBM and shale gas operations demonstrate that it is feasible to undertake deep drilling and associated activities in close proximity to housing with no breaches of strict planning conditions. The issue of noise with respect to environmental impact is discussed in greater detail in Chapter 6.
- 3.37. Hydraulic fracturing operations involve the use of multiple pumps to inject and pump back fluids. Again, the potential for noise from these operations has already been rendered compatible with planning conditions by use of acoustic insulation. This is exemplified by an established UK-wide industry that already undertakes 24-7 pumping of groundwater on a temporary basis – i.e. the construction dewatering sector: it requires all pumps to be acoustically insulated within housings that are sufficiently effective that no-one on site needs to wear ear protection, except for the engine maintenance technicians who occasionally access the interiors of the housings.
- 3.38. Concerns over the safety of methane handling are also routinely managed for other cases: 82% of Scotland's households are connected to the gas grid and use methane daily for domestic purposes (such as heating and cooking). As for gas wells themselves, safety procedures to prevent uncontrolled gas emissions are already stringent for purposes of workforce protection - this inherently safeguards the public who are further away from wellheads. There is an existing regulatory control over practices such as deliberate venting of methane, flaring of waste products, stripping out associated CO₂, or monitoring and control of unwanted seepage from boreholes.
- 3.39. Exploitation of unconventional gas onshore will also be constrained by practical issues, such as proximity to gas transmission pipelines or end-user premises such as the Grangemouth complex. Connecting gas sources into such infrastructure is likely to require at least some additional pipe-laying, which will entail negotiating wayleaves and planning permission.

3.40. Supply chain constraints may also act as a brake on unconventional gas development, as the UK (and northwest Europe more generally) is not well supplied with suitable onshore drilling rigs and suitably qualified and experienced rig crews. Although much of the required borehole hardware is also used offshore and is readily available from existing suppliers, most of these suppliers are based in the Aberdeen area, so delivery times and costs may be an issue for development sites in the Central Belt. Typically the UK has fewer than 10 (usually fewer than 5) rigs and crews available to undertake shale gas drilling. That contrasts with the USA, where up to 500 rigs with crews exist.

Conclusions

- By comparison with international precedents of coalbed methane and shale gas development, and considering Scotland's former coal mining and oil shale industries, it seems likely that unconventional gas *could* be developed in the country at a significant scale;
- None of the required technologies are particularly new, albeit they have yet to be applied at full-scale onshore in Scotland for these particular purposes. To date, there has been preliminary, exploratory drilling, for coal bed methane only, at only two sites (with a third under consideration), and pilot production at only one site (Airth). No full-scale commercial operations are yet underway in the UK, or globally;
- The economic viability of unconventional gas in Scotland will be inextricably linked into the regional price of gas in the north-western European market. If the USA begins to export gas at large scale in future, this price may be depressed, making it less profitable to exploit Scottish resources;
- The high population density of those parts of Scotland most likely to host significant onshore unconventional gas resources would be a challenge for any form of re-industrialisation, and will thus be so for a future unconventional gas industry;
- Experience of onshore drilling elsewhere in the UK, and of the largely safe, routine management of gas throughout urban Scotland, suggests that none of the particular issues raised by unconventional gas developments would be insurmountable, given adequate planning and effective regulation.

Introduction

4.1 There are a number of areas within Scotland that have the potential to yield unconventional hydrocarbon resources. This chapter is an assessment of the most likely geological units in Scotland with potential to host unconventional oil and gas resources, and seeks to highlight the knowledge gaps. This section examines coalbed methane, shale oil and shale gas. Tight oil and tight gas in sandstones are not included in this review - these are locations where oil or gas are conventionally contained in porous sandstones, but are unlikely to have sufficient permeability for commercial production.

Source Rock – Shale

4.2 Shale is a fine-grained, laminated sedimentary rock that is formed by the compaction of silt and clay sized particles and organic debris. Black shales can be rich in organic carbon. On heating during burial in the Earth's crust, these organic-rich sediments can produce oil and gas. Shale oil is produced by burial to depths where temperatures of around 60 – 160°C are reached (the oil generation window), and shale gas is generated at temperatures of around 150 – 200 °C (the gas generation window) during deeper burial. These products can be retained in the shale, even if the rock is uplifted to cooler temperatures.

4.3 Unlike conventional oil and gas bearing high-permeability sandstones, shales are rocks of naturally low permeability. However, organic-rich shales can contain significant amounts of free gas or oil within microscopic pores and fractures, and also bound oil or gas adsorbed onto the surfaces of organic matter particles. Horizontal drilling and hydraulic fracturing (fracking) can create new fractures and enhance the natural fractures within the shale, and permit recovery of gas and oil. To ensure sufficient flow rates of gas or oil to flow to the surface, a depth for shale of 1,500 metres below the land surface has been established in USA shale gas (Charpentier and Cook, 2011), and is suggested in the UK (Andrews, 2013).

4.4 Some organic shales can also be distilled to produce oil and gas, and this was done in West Lothian in the 19th and early 20th Centuries (see section 3.21 above), with the last operation closing in 1962.

4.5 Total production from Scottish oil-shale was estimated to be around 75 million barrels, with an estimated 37 million barrels still remaining (Cameron and McAdam, 1978; Hallett *et al*, 1985).

Potential source rocks for shale oil and shale gas recovery in Scotland

4.6 Experience from North America indicates the main geological criteria identified for successful shale exploration (DECC, 2010a) include:

- Shales containing more than 2% Total Organic Carbon (TOC);
- Organic matter type (Type I and II kerogen preferred);
- Depths from surface to the shale ranging from about 1,000 to 3,500 metres;

- Maturity of shale must be limited to the oil and gas windows (i.e. when the correct geological conditions exist for the thermal production of hydrocarbons) – this must have happened in the geological past, rather than under conditions present today;
- The presence of conventional oil and gas fields;
- The presence of oil or gas shows (leaks) from shales.

4.7 North American experience also indicates that shale gas well productivity is highly variable; gas from wells in ‘sweet spots’ can far exceed the average recovery from wells across an area. ‘Sweet spots’ tend to be areas where organic content, porosity and permeability are high, clay content is low, thermal history is favourable and the shale is highly ‘frackable’ (brittle with a high density of interconnected natural fractures).

4.8 For Scotland, there are very limited published data available to enable assessment of most of these criteria. There are few boreholes deeper than 1 km, and minimal modern seismic reflection surveys. Further research and exploratory deep drilling and production will be required before reserves can be estimated. The BGS has recently published a detailed study, which was commissioned by DECC, of the shale gas (but not CBM) and shale oil in place resource based on available data for the Central Belt of Scotland (Monaghan, 2014).

Shale occurrences in Scotland

4.9 Potential shale resources occur onshore or near-shore in three main geological settings in Scotland (Figure 4.1):

- Carboniferous rocks of the Midland Valley;
- Devonian rocks of Caithness, Orkney, and the Moray Firth coast;
- Jurassic rocks of the Inner Hebrides, Moray Firth and offshore basins close to the coast.

4.10 The lowest risk targets are likely to be those where shale is associated with conventional hydrocarbon discoveries, such as the Carboniferous shales of the Midland Valley.

4.11 The most likely geological settings which may have areas with potential shale gas or shale oil resources at depth are described in more detail below, in order of increasing exploration risk.

Carboniferous of the Midland Valley

4.12 Carboniferous rocks of the Midland Valley are the most likely targets for shale gas and shale oil exploration. The West Lothian Oil Shale Formation is likely to have the greatest potential as minor oil and gas discoveries have been made (Hallett *et al*, 1985; Underhill *et al*, 2008; Bide *et al*, 2008; Smith *et al*, 2008a, b, c).

4.13 At surface, the West Lothian Oil Shale Formation has not been heated sufficiently to produce oil or gas, but studies of outcropping rocks show that it is an excellent source rock for oil and gas with a Total Organic Carbon (TOC) content of up to 30% (Parnell, 1988). In comparison, US shales are as little as 2 – 3% TOC.

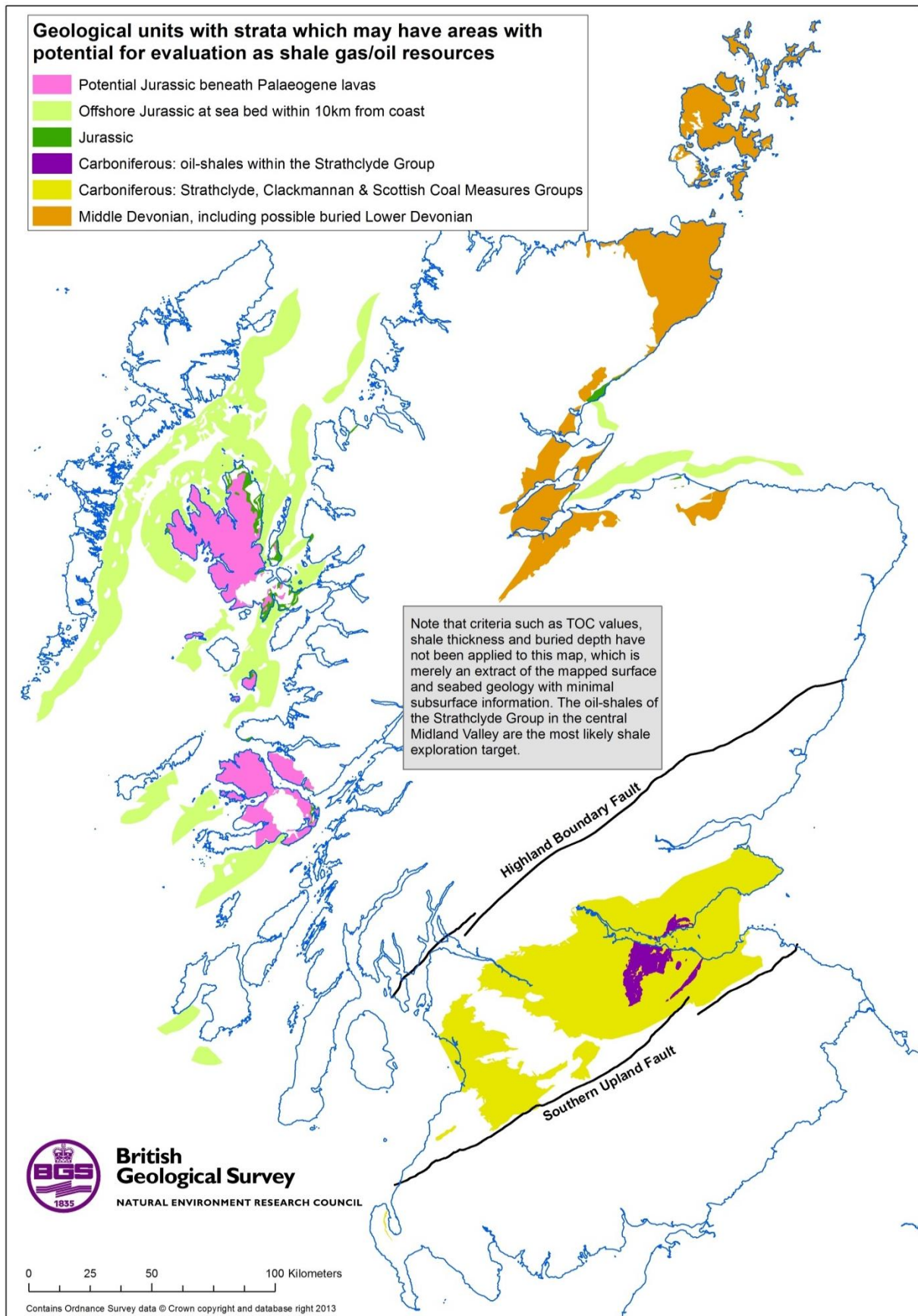


Figure 4.1. Map of geological units containing strata which may have areas with potential for evaluation as shale gas/oil resources. Note that criteria such as TOC values, shale thickness and buried depth have not been applied to this map, which is merely an extract of the mapped surface and seabed geology with minimal subsurface information. The oil-shales of the Strathclyde Group in the central Midland Valley are the most likely shale exploration target. The Shetland Islands are not included as the area is considered to be un-prospective for shale gas or oil (see section 4.17).

- 4.14 Up to thirteen organic-rich oil-shale seams with a combined thickness of around 35 m occur within the West Lothian Oil Shale Formation, which was originally deposited in a large stratified algal-rich freshwater lake or lagoon, termed ‘Lake Cadell’ (Cameron and McAdam, 1978; Read *et al*, 2002). The formation reaches a maximum thickness of 1,120m in the centre of the West Lothian basin around West Calder, but thins to the north, north-west and south (Browne *et al*, 1999).
- 4.15 Little is known about the extent of the Oil Shale Formation to the west of the outcrop, but if present, it is likely to be at considerable depth. Information from the BP Salsburgh 1A well, east of Airdrie, suggests that the West Lothian Oil Formation may be present in this area (Cameron and McAdam, 1978). This well produced 9,345 m³ per day (330,000 cubic feet per day) gas at about 850 m downhole on testing. Unfortunately the well was not logged to total depth so the identification of oil-shales in the well was derived only from drill cuttings (Department of Energy and Climate Change, DECC 2010b).
- 4.16 Other potential targets in Midland Valley Carboniferous strata include the organic-rich mudstones of the Gullane, Lower Limestone and the Limestone Coal formations. The Scottish Coal Measure Group rocks are unlikely to be buried to sufficient depth to be prospective for shale gas, but may be prospective for shale oil.
- 4.17 The DECC-commissioned report by the BGS provides 3D models and resource estimates for in place shale gas and shale oil (Table 4.1) and the distribution of areas considered prospective for shale gas or shale oil are summarised in Figure 4.2.

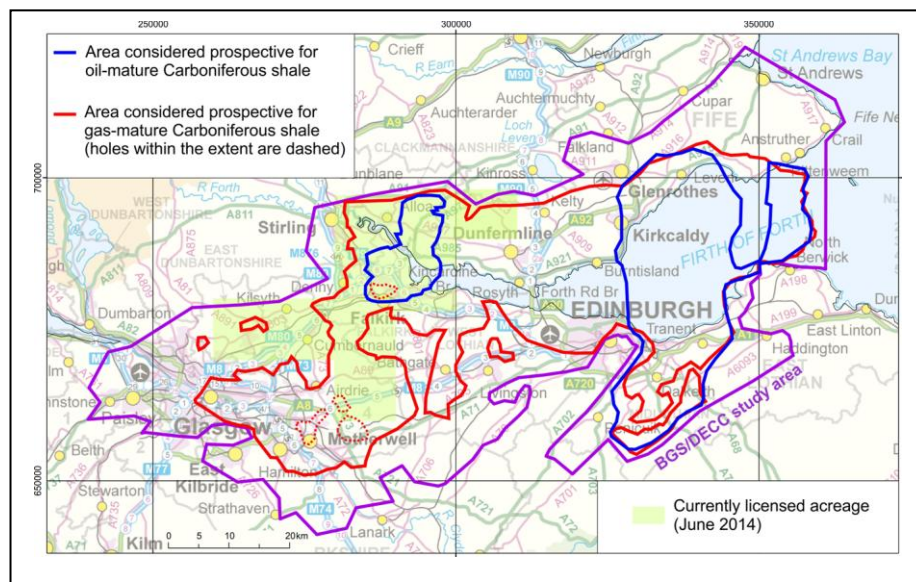


Figure 4.2 Areas of the Central Belt considered prospective for shale gas and shale oil (Monaghan, 2014)

	Total gas in-place estimates (tcm)			Total gas in-place estimates (tcf)		
	Low (P90)	Central (P50)	High (P10)	Low (P90)	Central (P50)	High (P10)
Shale gas	1.40	2.27	3.81	49.4	80.3	134.6
	Total oil in-place estimates (million tonnes)			Total oil in-place estimates (billion barrels)		
	Low (P90)	Central (P50)	High (P10)	Low (P90)	Central (P50)	High (P10)
Shale oil	421	793	1,497	3.2	6.0	11.2

Table 4.1 Estimates of the potential total in-place shale oil and shale gas resource in the Carboniferous Midland Valley study area (Monaghan, 2014)

Devonian of the Caithness, Orkney, and the Moray Firth coast

4.18 Shales are widespread within the Lower and Middle Devonian Old Red Sandstone rocks of the Orcadian Basin in Caithness, Orkney, Shetland Islands and the Moray Firth coast:

- Lower Devonian strata - The entire Devonian sequence exceeds 4,000 m in thickness towards the centre of the Orcadian Basin. If the geology identified offshore is extrapolated onshore, this may locally include significant thicknesses of Lower Devonian lacustrine shales, with possible shale gas potential (DECC, 2010a);
- Middle Devonian strata - The Caithness Flagstone Group of Orkney and Caithness and the overlying Eday Group of Orkney both contain organic-rich shales. Their potential for oil and gas was first investigated by Murchison (1859), and Parnell (1983) documented occurrences of hydrocarbons. More recently, these rocks have been intensively studied as geochemical data indicate they were a contributory source rock for the Beatrice oilfield in the Moray Firth (Bailey *et al*, 1990). The Lower Stromness Flagstone Formation has TOC values over 6%, whereas the Upper Stromness Flagstone Formation have an average TOC of 2.3%. These organic-rich lacustrine shales are about 160 m thick in total, but dispersed in units around 1.5 m thick within a total rock thickness of around 800 m (DECC, 2010a);
- Middle Devonian source rocks of the Orcadian basin are mostly still within the oil window today (Marshall *et al*, 1985) and are, therefore, unlikely to be productive for shale gas. However, they may have potential for shale oil. Shales within the Middle Devonian of Shetland have all been heated beyond 500 °C (Marshall *et al*, 1985), where most of the transformations from organic to gas have been completed, and hence are un-prospective for shale gas or oil.

Jurassic of Inner Hebrides, Moray Firth, and offshore Basins

4.19 Jurassic rocks, including shales, occur on the west coast from Mull to Skye and along the Moray Firth coasts. The most extensive outcrops occur on Skye and Raasay in the west and from Golspie to Helmsdale. A single 4 - 6 metre thick organic-rich shale within the Cullaidh Shale Formation at Elgol in Skye has a TOC of 5%, and black shale within the Brora Coal Formation at Brora has a TOC of 20% (Hudson and Trewin, 2002).

- 4.20 On Skye, Eigg and Mull, Jurassic rocks are overlain by volcanic rocks of Palaeogene age (Emeleus and Bell, 2005; Hesselbo *et al*, 1998). The extent of the Jurassic rocks below the underlying volcanics is not known, but may represent a potential shale gas/oil exploration target.
- 4.21 Extensive areas of Jurassic rock are developed under the sea in the Inner Hebrides, Sea of the Hebrides, West Shetland and Moray Firth basins. These may be potential shale gas/oil exploration targets, particularly if developed from land.

Coal Bed Methane (CBM) Resources

- 4.22 Coal is a sedimentary rock composed mainly of carbon derived largely from plant material deposited in ancient tropical forests. CBM is a gas found naturally within coal seams. Typically it consists of 80 – 95% methane, the remainder being other hydrocarbons, nitrogen and carbon dioxide, together with traces of argon, helium and hydrogen (Creedy, 1991).
- 4.23 An assessment of new coal exploitation technologies in the UK was carried out by BGS for the former Department of Trade and Industry (Jones *et al*, 2004). It was estimated that the total CBM resource in the UK is 2.9 trillion m³ (102 tcf), and that the recoverable part of the resource is unlikely to exceed 1% of this resource due to low seam permeability, low gas content and planning constraints. No separate figure is available for Scotland. From areal estimates of resources (DECC, 2010), it is possible that Scottish resources are just 22% of those of the whole UK.
- 4.24 However, DECC (2010) report that USA CBM developments have now been proven to achieve recovery of 30–40% in some fields and suggest that if 10% of the UK CBM resource potential could be developed, this would be equivalent to over three years of UK natural gas supply. This has not yet been tested by extensive UK drilling or production.
- 4.25 Development of commercial CBM would be required before a more reliable reserve estimate can be made as this would provide data on important factors such as: coal permeability, gas content, gas saturation from cores, well density, permit costs, environmental studies and mitigation costs, production profiles, and costs of drilling (DECC, 2010).
- 4.26 Potential CBM resources in Scotland are likely to be found in the Midland Valley, within the Limestone Coal Formation of the Clackmannan Group and the younger Scottish Coal Measures Group. Other resources may be present with the Coal Measures Group in the Canonbie area, east of Dumfries (Figure 4.3).
- 4.27 Jones *et al* (2004) regard the Limestone Coal Formation as the main CBM target in Scotland and the Clackmannan Coalfield as probably the most prospective of the Midland Valley coalfields.
- 4.28 Seam methane contents of 8 – 10 m³/tonne have been reported from ten seams 850 – 900 metres deep within the Limestone Coal Formation at Airth, south-east of Stirling, where significant gas and water production has been established from Dart Energy (formerly

Composite Energy) CBM wells (Bacon, 1995). No public domain information on the gas content, permeability or water and gas production of the Airth wells is currently available (DECC, 2010).

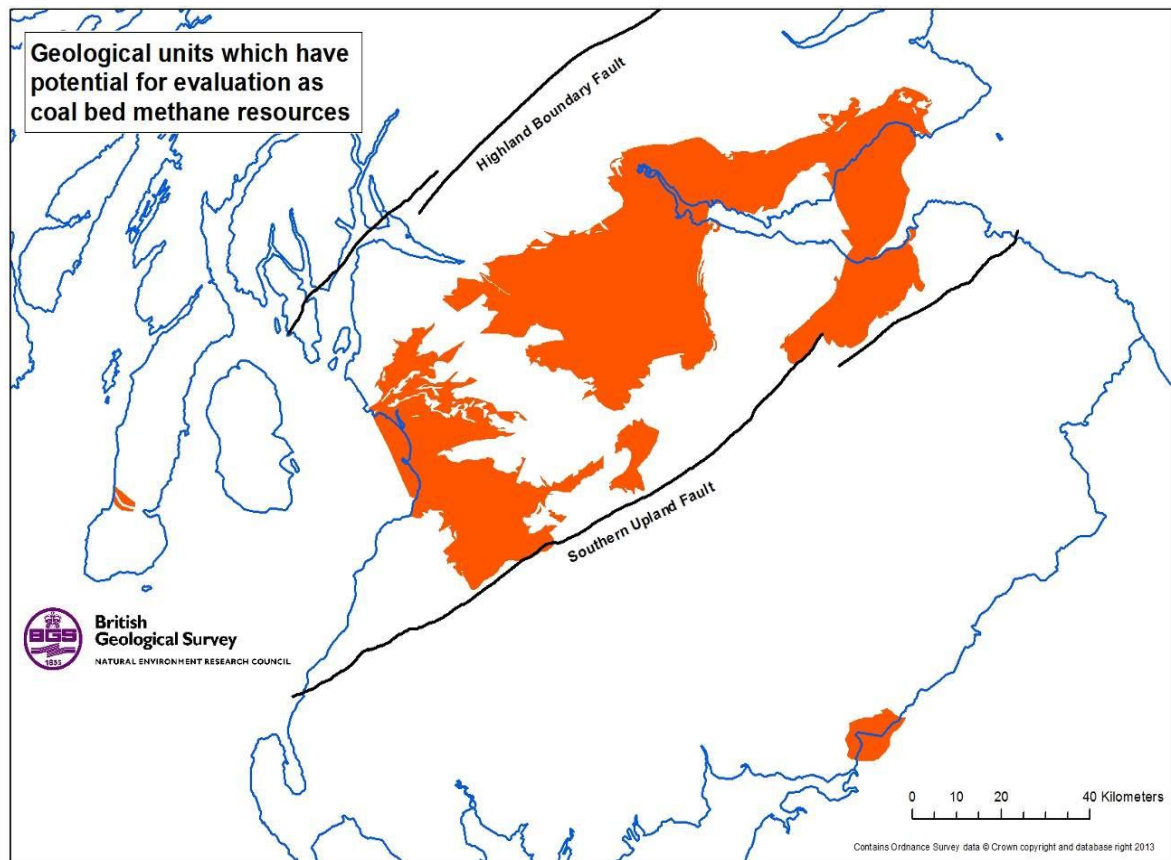


Figure 4.3. Areas of the Midland Valley of Scotland with the surface, proven and possible subsurface occurrences of the Clackmannan and Scottish Coal Measures Groups which have potential for evaluation as coal bed methane resources. More detailed information on areas likely to have the highest potential for CBM is available on the detailed maps produced by Jones *et al.* (2004).

Conclusions

4.29 The most likely geological settings that may have areas with potential shale gas or shale oil resources at depth, in order of increasing exploration risk, are:

- Carboniferous Strathclyde Group of the Midland Valley, specifically the West Lothian Oil Shale Formation;
- Lower and Middle Devonian rocks of Caithness, Orkney and the Moray Firth coastal areas;
- Jurassic rocks along and the west coast from Mull to Skye and east Sutherland, and offshore Jurassic rocks close to the shore.

4.30 Proven CBM resources have been found within the Limestone Coal Formation at Airth, south-east of Stirling, and this formation is regarded as the main CBM target in the Midland Valley. The Clackmannan Coalfield is probably the most prospective of the Midland Valley coalfields for CBM resources. Other resources may be present with the Coal Measures Group in the Canonbie area, east of Dumfries.

5.1 The Expert Scientific Panel has identified the following technological areas that pose important challenges in carrying out shale gas and coal bed methane recovery.

- Drilling;
- Hydraulic Fracturing;
- Seismicity;
- Well Integrity;
- Gas Production;
- Water Sourcing;
- Wastewater Disposal;
- Well Abandonment.

5.2 An outline of the main technical challenges is given with comment on their cause, how they are currently tackled and their implications.

Drilling

5.3 Once a gas prospect is identified, a well must be drilled to assess gas content and determine how readily it can be produced. In the early days of the oil industry, wells were almost entirely vertical. Wells are cased with metal tubes and the space between the tube and the drilled hole in the rock is cemented all the way down to the reservoir.

5.4 In the cased and cemented zone, it is critical that there is no flow between the wellbore and the surrounding rock, since leakage into the surrounding rock strata is undesirable. This is especially true in the shallower subsurface, where such leaks could potentially contaminate any freshwater aquifers traversed by the boreholes.

5.5 In the reservoir zone, i.e. in the coal for CBM or the shale for shale gas, the well is “completed” such that flow between the reservoir and the wellbore takes place. Most wells into shale gas and CBM formations are horizontal, in that the well is drilled vertically to a depth some distance above the reservoir and then steered to gradually follow the horizontal direction of the gas-bearing strata. The horizontal section of these wells are often 1 to 3 km in length which allows contact with a larger amount of reservoir rock than vertical wells, thus increasing gas production.

5.6 Drilling presents a number of technical challenges. Hard rocks, such as sandstone, are more difficult to drill through and therefore the hole is drilled more slowly and uses more drill bits. However, the final hole is stable and generally does not collapse. Softer rock, such as shale and coal, are much easier to drill but holes are more liable to collapse due to the low strength (as measured by uniaxial compressive strength). Borehole stability – not least during shale gas drilling – is well understood, and modern drilling, well completion techniques and drilling fluids have rendered it a relatively small problem.

Hydraulic Fracturing

- 5.7 According to the US Department of Energy (2013), around 2 million oil and gas wells in North America had been hydraulically fractured by 2013. Despite this, the design and execution of the hydraulic fracturing in shale reservoirs remains a technical challenge - the main objective being to yield the maximum amount of gas over a reasonable time with the fewest hydraulic fracturing jobs.
- 5.8 The process of hydraulic fracturing is broadly understood and models exist to design such jobs, while extensive oil industry experience exists in carrying them out. However, the process is not quantitatively predictable.
- 5.9 Hydraulic fracturing is typically carried out in a number of steps, as described in Chapter 3. Treatments vary in response to factors such as reservoir thickness, depth below the surface and mechanical properties. This involves designing the volume, the applied pressure and the specification of fluid.
- 5.10 The technical challenge is to design optimal “fracking jobs” so that the operation produces as much gas as possible from a single fracture treatment. The process is typically monitored by acoustic techniques. There is extensive industrial experience of how to control the process and maximise gas production.
- 5.11 The success of fracking in relation to the formation of the fractures in the rock depends on some shale properties, such as the brittleness. This in turn may depend on the sand content of the shale, relative to clay. These factors affect how easily and extensively the shale fractures. If productive shales are discovered in Scotland, then precisely how these are optimally fractured must be established. Despite decades of industry experience, the details of the fracture pattern and placement are not yet accurately predictable.
- 5.12 The consequences of sub-optimal fracking will be that wells do not produce as much gas as possible. This could lead to re-fracking operations earlier than had been anticipated.

Seismicity

- 5.13 When wells are fractured, the rock breaks and causes small locally detectable, acoustic (seismic) events. The fracking process induces many small local seismic events in the rock. These micro-seismic events cannot be detected with conventional equipment used for earthquake detection. However, downhole micro-seismometers or local arrays of sensitive micro-seismic detectors on the surface above the fracking location are used to detect and map the distribution of seismic events in 3D in order to direct and monitor the fracturing process.
- 5.14 The shales and surrounding rocks are under natural stresses and the hydraulic fracturing may trigger their release. Two earthquakes measuring 1.7 and 2.3 M_L on the Richter scale were induced during fracturing operations by Cuadrilla in North-West England in April and May 2011. However, because the Richter scale is a logarithmic measure of magnitude, rather than a linear scale, the energy released by the 2.3 M_L event was actually 4 times

greater than the 1.7 M_L earthquake. These events are most likely to have occurred on a pre-existing geological fault that was already close to slipping (Green *et al*, 2012).

5.15 These events are significantly smaller than the natural seismicity of the region. The largest recent event occurred in 2009 and measured 3.7 M_L . This caused no damage to property or to the safety of local population. The British Geological Survey seismic network does not usually detect magnitudes below 2.5 in urban areas due to the background vibrations from traffic.

5.16 The technical challenge to avoid larger seismic events depends on:

- developing a good knowledge of the direction of existing principal stress fields in shale formations;
- knowledge of the mechanical properties of the shale and surrounding rock;
- mapping the positions of pre-existing faults, and their relationship to the applied stress (i.e. how close they are to failure).

5.17 This is precisely the same information required to carry out efficient fracturing operations, and there is a clear incentive to gather these data in order to optimise hydraulic fracture design (see above). In the early stages of exploration and appraisal, such data may be unavailable. The monitoring of micro-seismic events during fracturing operations may eventually determine how best practice (in terms of both avoiding larger seismic events and optimising fracking design) is established.

5.18 Stress-release seismic events occur in “near critical” systems, which are not intrinsically predictable. For example, the relationship between magnitude and frequency of earthquakes is established for most seismically active regions. However, they cannot predict where or when earthquakes will occur. The low energy seismic events arising from hydraulic fracturing do not pose the same danger to human life as major earthquakes. For example, an earthquake measuring 5 – 6 M_L on the Richter Scale would cause some damage to poorly constructed buildings with a relatively low number of potential casualties. However, this would have about 4,000 times greater energy than the larger of the two fracking-induced earthquakes in NW England in 2013.

Well Integrity

5.19 Well integrity is important to ensure that no gas leakage occurs during production, or injected fluid leakage during the injection period of the hydraulic fracturing operation. The well is lined (i.e. cemented and cased as described previously) throughout its entire length and is completed (where flow can occur between the rock/coal/shale and the wellbore) in the reservoir section (Figure 5.1). Clearly the reservoir section has to “flow” in order to produce gas, but exchange between the main surface to reservoir section of the well should not flow (see Paragraph 5.4 above).

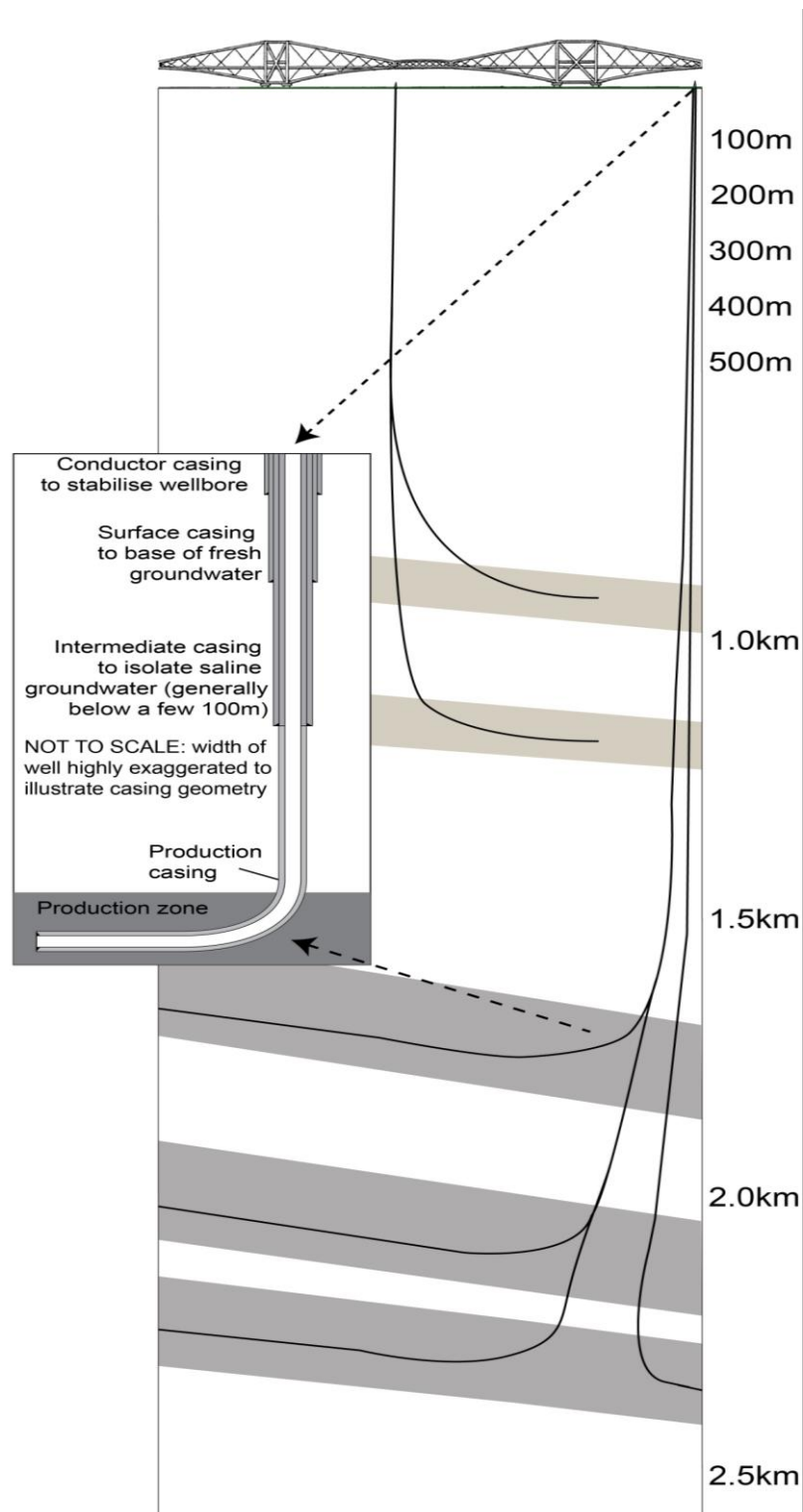


Figure 5.1: Scale drawing of shale gas and coalbed methane wells (black lines) coming from a stacked multi-well, multi-lateral well pad. Drill rig is about 10 m tall, note that a workover rig could be up to 20 m tall. Image of the 110 m high Forth Rail Bridge from 1911 Encyclopedia Britannica (licensed under Creative Commons) is provided for scale. The width of the black lines representing the wellbores in this image are wider than the wellbores would be at this scale - the diameter of the production casing is typically of the order of 14cm. Note that the geology is deliberately simplified: in the Central Belt prospective shale units are 2 - 3m thick and packaged within thicker interlayered units of “sandstones and shales” (Monaghan, 2013, Underhill *et al.*, 2008). The details of the geology of other prospective areas in Scotland will remain unclear until such time as any exploration drilling takes place. The inset shows a typical well design (after Mair *et al.*, 2012). Conductor casing is set for a depth of approximately 30 metres to stabilize the hole. The surface casing runs from the surface to beyond the lowest freshwater-bearing rocks. The intermediate casing isolates the borehole from non-freshwater zones. The production casing runs all the way to the production zone. At each stage cement is pumped into the wellbore and up between the casing and the rock until it reaches the surface. Geophysical tools are run down the hole to test for cement integrity before the next wellbore is drilled and cased. Horizontal wells for CBM will typically be at shallower depths (about 1 km) than shale gas wells (about 2 km), as shown in the diagram.

5.20 Poor well construction could lead to gas leakage into groundwater. There is evidence to suggest that gas leakage may have occurred during operations in the Marcellus Shale in the United States, where methane enrichments have been observed in aquifers within 1 km of wells (Jackson *et al.* 2013). However, detailed gas chemistry and isotopic analysis is required to establish whether these enrichments exceed natural background levels (Molofsky *et al.* 2011). It is important to note that virtually zero emissions of methane are technically achievable using best practice well construction and gas monitoring methods. There is no evidence to suggest that leakage of fracking fluids has led to increased levels of chemicals, salts, metals or radioactivity in near-well groundwaters (e.g. Warner *et al.* 2012).

Gas Production

5.21 The prediction of the precise amount of gas that can be produced from a well is difficult. Estimates are often made by gas reservoir engineers by comparing the reservoir with analogues (for example, similar ancient sedimentary rocks that crop out on the Earth's surface and are much easier to study). Typically gas production is matched using models, then used to predict future treatments. However, the main objective from an operational point of view is that the level of gas production over the period is at an economic volumetric flow rate.

5.22 The consequences of poor prediction of gas production are mainly economic. If the predictions are too optimistic, then operators will not make as much money as anticipated – and more frequent fracking treatments will be required. If the gas volume is under-predicted and more gas is produced than anticipated, then the design of the production facilities may not be optimal and issues, such as water handling capacity, may ultimately affect production levels. If more fracking treatments than anticipated are required, this may also have environmental consequences, such as increased traffic and noise levels.

5.23 During the early period of a shale gas operation, the flow-back produces a significant amount of water, much of which was injected in the fracking operation. This interferes with the production of gas. After a period of injected water production, the gas production rises to a peak. This is followed by a period of declining gas production, during which the gas flow rate gradually reduces to an uneconomic level. This occurs since the gas in the formation (which can flow to the induced fractures) has depleted and gas from further away takes longer and comes at a lower flow rate.

Water Sourcing

5.24 Normal CBM extraction methods do not require significant volumes of water during drilling or extraction. In contrast, hydraulic fracturing requires large volumes of water. The volume of water required depends on a number of factors, such as reservoir geology, well depth, well length and the number of fracturing stages. Typically 40,000 - 300,000 gallons (180,000 – 1.36 million litres) of water may be required to fracture one well in a coal bed formation, while 2 to 4 million gallons (9.1 – 18.2 million litres) of water may be necessary to fracture a horizontal well in a shale.

5.25 Onshore operations typically use either mains water, or water abstracted from surface reservoirs or shallow aquifers. The water is required intermittently, usually during the drilling and fracturing stages of operation. Strategies can be employed to avoid water

stress, such as scheduling operations to avoid periods when water supplies are low and by using alternative sources, e.g. seawater (Harris and van Batenburg 1999) or saline water from deep aquifers (Yost 2011). Current CBM operations in Scotland do not appear to need hydraulic fracturing, thus water requirements would likely be modest and could be provided via existing underground water mains pipes.

Wastewater disposal

- 5.26 Water injection for hydraulic fracturing of shales results in the production of significantly more wastewater than CBM extraction. Typically 25 - 75% of the water injected during hydraulic fracturing returns to the surface during gas production - typically 0.5 - 3 million gallons (2.3 – 13.6 million litres). The volume of returned water depends on shale geology, type of fracturing fluid and the fracture design.
- 5.27 Hydraulic fracturing fluid usually includes between three and twelve chemicals depending on the characteristics of the water and the shale being fractured. Each component serves a specific purpose. A table of additive type, main chemical compounds and common use for hydraulic fracturing has been published by the United States Department of Energy (US DOE, 2009). The chemicals used during hydraulic fracturing are typically at low concentrations (0.1 to 0.5%).
- 5.28 The water produced during CBM extraction was originally present in fractures and pores prior to drilling. They are typically much more saline than fracking fluids. While fracking fluids may contain 1,500 – 8,000 ppm of additives, produced brines have total dissolved solids from 30,000 to 150,000 ppm (McElreath, 2011). Produced waters contain natural organic compounds, salts, low levels of naturally occurring radioactive materials (e.g. ^{238}U , ^{232}Th , ^{40}K) and microorganisms (USGS Factsheet FS 156-00). Inappropriate disposal of these fluids in the US has had negative environmental consequences (Adams, 2011).
- 5.29 Wastewater disposal – from shale gas production or CBM – requires storage, clean up and transportation, as well as safe and efficient disposal. Wastewater is ultimately a by-product of many industrial processes and treatment and disposal are heavily regulated in UK. This is discussed further in Chapter 7, with regards to unconventional oil & gas developments. Consequently, they are unlikely to present significant technical challenges, although they do represent costs to the operator.
- 5.30 After clean up, wastewater is typically released into rivers or pumped to sea. Underground injection is used in the US, but this process may be the cause of small earthquakes (NRC, 2012).

Well abandonment

- 5.31 When oil and/or gas wells come to the end of their productive life they are shut in, and then abandoned. Abandonment should be carried out such that wells do not represent a safety or environmental hazard, i.e. they should not leak hydrocarbons.
- 5.32 Concern has been expressed about the safety and environmental issues regarding abandoned wells and the UK (and all other countries) has regulations which operators must

follow. The regulations also apply to shale gas and CBM wells. Since these are on land and often close to population centres, the issue of well abandonment has been raised in debates on shale gas development. Several hundred onshore UK wells have been successfully plugged, capped and abandoned, though in some cases the procedure may have been defective and some wells have leaked.

5.33 A recent review by Davies *et al* (2014) collated data on the integrity of (mostly) conventional oil and gas wells from around the world and made recommendations for future onshore UK unconventional oil and gas wells.

5.34 However, an important point to note is that conventional oil and gas wells are over-pressured prior to exploitation, and in some cases remain so after the end of economic production of hydrocarbons. In this case, if the well is left open, oil and/or gas will flow out due to the pressure being above hydrostatic.

5.35 In contrast, shale gas and CBM wells are by definition under-pressured and they do not naturally flow, unless the formation is massively fractured or the coal seam is dewatered - gas is then produced for a period until the pressure drops again (see Thorogood and Younger, 2014). Consequently, unconventional oil & gas wells should be much easier to deal with as long as the regulations are adhered to and monitoring is implemented.

Conclusions

5.36 There are a number of technical challenges associated with unconventional hydrocarbon extraction however, given the extensive experience of the oil and gas industry, none of these are seen as insurmountable.

5.37 Shale gas and CBM wells are under-pressured and methane does not flow naturally, which contrasts with the situation found in conventional gas wells. Therefore, it should be easier to deal with the abandonment of unconventional oil and gas wells, provided regulations are adhered to and monitoring is implemented.

Introduction

- 6.1 The extraction of unconventional oil & gas is ultimately an industrial process and, as with most, if not all, industrial processes, there will be some environmental impacts. There are a number of areas where the environment in the vicinity of operations may be impacted by unconventional oil & gas operations, including the surface and subsurface water environment, the air environment and the geological environment around wells. Globally, extraction and use of unconventional hydrocarbons may impact on the atmospheric greenhouse gas balance.
- 6.2 Additionally, as with any industrial development, there may be both positive and negative social impacts associated with the unconventional hydrocarbon industry. The social and public health impact of development is dependent on the demographics and economics of the area in which it is being developed.
- 6.3 This chapter reviews a suite of potential problems. However, it should be noted that the existence of a potential problem does not mean that it will occur. There are numerous regulations and assessments in place to reduce, or eliminate, adverse occurrences.
- 6.4 In the case of societal impacts, early and continued consultation should aim to minimise adverse impacts and maximise local enhancement (see chapter 8 for more details).
- 6.5 In this Chapter, the Expert Scientific Panel has reviewed the following main environmental challenges associated with unconventional oil & gas operations:
- Impacts on the water environment;
 - (i) Water usage and associated pressures;
 - (ii) Management of hydraulic fracturing fluids;
 - (iii) Management of wastewater.
 - Naturally Occurring Radioactive Materials (NORM);
 - Seismic activity;
 - Noise from site activity and increased traffic;
 - Light pollution;
 - Landscaping and visual impact;
 - Air emissions and air quality;
 - (i) Direct Air Emissions
 - (ii) Indirect changes to air quality
 - (iii) Compatibility with Scottish Government greenhouse gas (GHG) reduction targets;
 - Baseline characterisation, post production remediation issues and reinstatement of assets.
- 6.6 The descriptions of these environmental challenges should be read in conjunction with Chapter 7, which outlines the regulatory system in place to mitigate these challenges.
- 6.7 Additionally, the Expert Scientific Panel has considered the following societal challenges (adapted from the Australian Council of Learned Academies, Cook *et al* (2013)):

- population growth and a changed demographic profile;
- upwards and downwards pressures on property values;
- concerns about community health, safety and wellbeing.

Impacts on the water environment

6.8 Unconventional hydrocarbon extraction can both produce and consume water. In considering the environmental challenges of unconventional hydrocarbon extraction to water quality and resource integrity, the following are key areas of focus (AEA, 2012a):

- borehole drilling;
- upstream acquisition of water;
- chemical mixing of the fracturing fluid;
- injection of the fluid into the formation;
- the production and management of flowback and produced water; and
- the ultimate treatment and disposal of produced and hydraulic fracturing wastewater.

6.9 If inappropriately controlled, unconventional gas operations can impact groundwater and surface water quality, with key impacts being:

- aquifer cross-contamination due to poor borehole construction;
- pollution from unplanned release of gas, drilling fluid or fracturing fluid into other parts of the water environment;
- surface spills from storage tanks and lagoons, from fluids and chemicals used in drilling and fracturing or of produced or flowback waters;
- pollution from unauthorised disposal of liquid or solid waste containing potentially polluting substances;
- abstraction of quantities of water that could lead to an unacceptable impact on the environment; and
- contamination that could arise from the construction and removal of infrastructure, including that which could link between different boreholes across the drilling area.

Water usage and associated pressures

6.10 The water requirements for shale gas and coal bed methane operations vary significantly due to the fundamentally different ways in which these processes are undertaken. Coal bed methane extraction involves essentially a dewatering process, whereas shale gas operations require water for the hydraulic fracturing process. This results in some similar, and some divergent, environmental impacts.

6.11 Sourcing of water is an important factor to consider. In Scotland, the vast majority of water is normally supplied from surface sources, although the industry may still wish to abstract groundwater for logistical reasons.

6.12 There are a number of potential environmental impacts associated with surface water and groundwater abstraction. If not subject to control, there could be impacts on river flows, groundwater levels or other water features such as lochs or wetlands. In turn,

reduced water level could have adverse hydro-ecological impacts. Further, surface water withdrawal may affect recharge to groundwater. Lowering of the water table through abstraction of groundwater could encourage the intrusion of saline water into non-saline groundwater.

- 6.13 However, as detailed in Chapter 7, the abstraction of water is tightly regulated in Scotland to prevent or minimise unacceptable impacts to the wider water environment, including other water users and water dependent ecosystems.

Hydroecological functioning

- 6.14 Linking infrastructure (e.g. pipes to transport extractive products to a processing plant) may bisect important biodiversity corridors which improve biodiversity in fragmented landscapes. These corridors increase animal movement between patches, and facilitate pollination and seed dispersal (Tewksbury *et al*, 2002).
- 6.15 The burying of infrastructure may remove a surface barrier. However, if the infrastructure is protected by material of different hydraulic conductivity, this network may function as a preferential flow pathway or acts as a barrier to flow. That response could induce changes or surface flows or groundwater levels, which could have an adverse environmental impact.

Management of hydraulic fracturing fluids

- 6.16 To date, the only company in the UK to have carried out hydraulic fracturing as part of shale gas operations is Cuadrilla Ltd. Hydraulic fracturing was undertaken for coal bed methane using only water and sand at Airth in the mid-1990s (DECC, 2010) and by Scottish Water to increase borehole yields for public water supplies, for example at Laggan Bridge and Alligin (Cobbing *et al*, 2007).
- 6.17 Substances added to fracturing fluids can be found in a number of different products and applications, see for example Table 3.3 in Pearson *et al* (2012), which provides an overview of the substances and their other common uses. Cuadrilla Ltd (2014) indicate that their fracturing fluids will comprise mostly water and sand (99.95%) with one or more of the following chemical additives:
- polyacrylamide friction reducers (0.04%);
 - sodium chloride (0.00005%);
 - hydrochloric acid;
 - biocide, for when the water provided from the local supplier needs to be further purified and to kill bacteria that can produce hydrogen sulphide gas.
- 6.18 Only polyacrylamide has been used by the company to date (Cuadrilla Ltd, 2014). Substances added to the fracturing fluids are subject to the CAR licensing requirements (Chapter 7 provides further detail on this licensing regime).
- 6.19 Surface spills of fracturing fluid may pose a greater contamination risk than hydraulic fracturing itself (Mair *et al*, 2012). Additive chemicals will generally be delivered and stored

in concentrated form before being diluted to low concentrations with water to form fracturing fluid, which may then be stored in large tanks on site.

- 6.20 To mitigate spills, established best practices are generally incorporated in the regulatory consents. These include using non-hazardous chemicals wherever possible, storing them away from surface waters and important aquifers, ensuring sites are protected with impermeable liners and ensuring all stores of hazardous liquids are double-bunded as a precaution against leaks (Mair *et al*, 2012).
- 6.21 These practices will be beneficial for mitigating spillage of other chemicals that are stored on site, for example gas treatment chemicals which are used to 'sweeten' the gas as part of the clean-up before input to a national pipeline network. The regulations in place to mitigate these risks are described in Chapter 7.

Management of wastewater

- 6.22 Flowback waters and produced waters may contain fracturing/drilling fluids, natural inorganic and organic substances, and naturally occurring radioactive materials (NORM). SEPA analysed water abstracted from exploratory drilling at DART Energy's coal bed methane exploration site at Airth. The water contained NORM, chloride, alkalinity (as calcium carbonate), iron, aluminium, nickel, zinc, lead and a number of organic compounds (benzene, xylene, naphthalene) and had electrical conductivity (a measure of dissolved charged substances), consistent with water from coal beds that are higher in dissolved material (SEPA, 2013).
- 6.23 The Environment Agency analysed flowback water from exploratory drilling and fracturing by Cuadrilla at Preese Hall, Lancashire, and found substances typical of water coming from shale rock including sodium, chloride, bromide, iron, zinc, arsenic, lead, magnesium and chromium as well as NORM (Environment Agency, 2011).
- 6.24 The change in composition of flowback and produced water (in a hydraulically fractured site) from their pre-extraction composition means that, under existing regulations, both would now be regarded as waste and may require treatment prior to discharge back into the environment. Thus, unless there is illegal disposal of fluid or an undetected or mitigated leak, the environmental impacts of disposing of produced or flowback waters should be minimal given existing regulation in Scotland.

Naturally Occurring Radioactive Materials (NORM)

- 6.25 Naturally Occurring Radioactive Materials (NORM) are ubiquitous in the environment and are present in many geological formations, including oil- and gas-bearing rock strata. Produced water abstracted from coal seams may contain NORM, as may flowback fluids that are generated during hydraulic fracturing. NORM are also likely to be present as insoluble sediments and scales that adhere to the surface of gas or water process vessels and pipework.
- 6.26 NORM abundance depends on the geochemistry of the reservoir and the volume of water circulating through that reservoir. Shale beds already contain water (the formation water) but the volumes are less than formation water in offshore hydrocarbon reservoirs.

Therefore, the concentration of NORM from shale bed formation water is expected to be much less than with the very large volumes of water associated with offshore oil production.

6.27 If NORM is above levels where regulation is required, contaminated vessels and pipework must be taken to specialist clean-up facilities, where the radioactive scale is removed, before disposal in a UK landfill regulated by one of the UK environment agencies. Flowback and produced waters containing NORM must also be treated. Thus, disposal of solid or liquid waste containing NORM could increase the risk of radiation exposure, but the regulatory framework, described in Chapter 7, ensures that this risk is minimised by keeping levels within acceptable limits.

Seismic activity

6.28 Felt seismicity (i.e. that can be felt by people at the surface as opposed to microseismicity from an individual fracture) has been observed with both hydraulic fracturing to extract unconventional hydrocarbons and during disposal of waste fluids into sub-surface geological strata (Mair *et al*, 2012). However, it is worth noting that the latter practice is not allowed in Scotland under the EU Water Framework Directive.

6.29 As described in Chapter 5, hydraulic fracturing of the Bowland Shale caused two seismic events in the Blackpool area of 2.3 M_L and 1.5 M_L (Green *et al*, 2012). This led to the temporary moratorium on hydraulic fracturing introduced by the UK Government from November 2011 to June 2012.

6.30 Data compiled from American sources suggests the Blackpool hydraulic fracturing event was unusually large, and induced-seismicity associated with hydraulic fracturing is typically less than 0.75 M_L (Davies and Foulger, 2012). Natural events of this size occur hundreds of times each year and are felt by very few individuals (Mair *et al*, 2012).

6.31 However, with the recognition that activity associated with hydraulic fracturing could generate felt seismicity, the Department of Energy and Climate Change has proposed that operations be halted and remedial action implemented if events of magnitude 0.5 M_L or above are detected (Green *et al*, 2012). The DECC 'traffic light' monitoring system is discussed in Chapter 7.

6.32 Whether 0.5 M_L is an appropriate level or not is subject to debate, with higher limits (e.g. 0.75 M_L) advocated, based on large data sets documenting typical induced seismicity elsewhere (e.g. Davies and Foulger, 2012; Westaway and Younger, 2014). These limits are viewed as pragmatic substitutes for true predictive understanding of local stress processes in the UK subsurface.

6.33 Better practice could be to use ground surface velocities rather than source magnitude (Westaway and Younger, 2014), to consider seismic limits in relation to natural seismicity based on historical instrumental records, and to understand if there is any cumulative effect of small tremors leading to larger events. The need for continued monitoring of the seismic effects is a reasonable expectation, both during borehole drilling and hydraulic fracturing and, if multiple hydraulic fracturing boreholes are operated, for up to 30 years after hydraulic fracturing was undertaken. The present evidence, from many decades of

UK coal mining and deep drilling onshore, is that seismic effects are expected to be small in magnitude.

- 6.34 Establishing acceptable limits of seismicity prior to initiating hydraulic fracturing may also encourage developers to adopt practices to mitigate induced seismicity e.g. minimising pressure changes at depth (Zoback, 2012). The limits set are likely to be conservative if compared to natural seismicity. For example, the Blackpool area is of low natural seismicity and these atypical induced seismic events were within the range of natural seismicity recorded in this area, 2.5 – 4.4 M_L .
- 6.35 In Scotland, natural (background) earthquake activity almost all occurs north of the central belt, or south of the Southern Uplands (Figure 6.1). There is a concentration of natural seismicity on the west side of Scotland due to uplift of the land surface since the last glaciation, and effects due to movements of tectonic plates. The coal mining induced seismicity is mainly associated with the Midlothian and Clackmannan coalfields. Most of these events occur at shallow depths and are small, not exceeding magnitudes of around 3 M_L . Natural earthquake activity tends to occur deeper in the crust where the rocks are much stronger.
- 6.36 Oil and gas extraction (fluid withdrawal) from a reservoir can potentially induce felt seismic events. These events are rare relative to the large number of oil and gas fields around the world (NRC, 2012). It is unlikely that seismicity would be experienced with the extraction of CBM, which does not generally require hydraulic fracturing. In CBM extraction, other than the initial drill fluid, there is no introduction of additional liquid capable of lubricating planes under stress that can move and cause seismicity.

Noise from site activity and increased traffic

- 6.37 Environmental noise from unconventional gas sites has the potential to impact on local residents and wildlife (AEA, 2012a). For a shale gas site consisting of 10 wells, it is estimated that 800 to 2,500 days of activity may be needed to undertake ground works, road construction and the hydraulic fracturing process (AEA, 2012a). These activities may generate levels of noise in locations that had previously experienced relatively low background noise levels.
- 6.38 This may be more noticeable in rural areas than on a brownfield or industry fringe site. For example, the noise limit for Cuadrilla in Balcombe is 42 dB (decibels) at night and weekends, and 55 dB from 7.30am to 6.30pm weekdays for all operations. For comparison a normal conversation at 1 metre distance is between 60 and 65 dB.
- 6.39 During well-drilling activities, hydraulic fracturing and production pump and/or engine operations are likely to be the primary sources of noise (AEA, 2012a). Drilling occurs 24 hours a day, typically for four weeks per well. However, drilling can be a relatively quiet activity (such that rig hands do not need ear guards) and diesel engines can be housed in acoustically insulated boxes. Further, these estimates of activity time come from hydraulic fracturing for shale gas extraction. Given the shallower drilling depths required for coal bed methane and the significantly reduced need for imported water, it is likely this will require less activity and therefore generate less noise and/or operate for a shorter period.

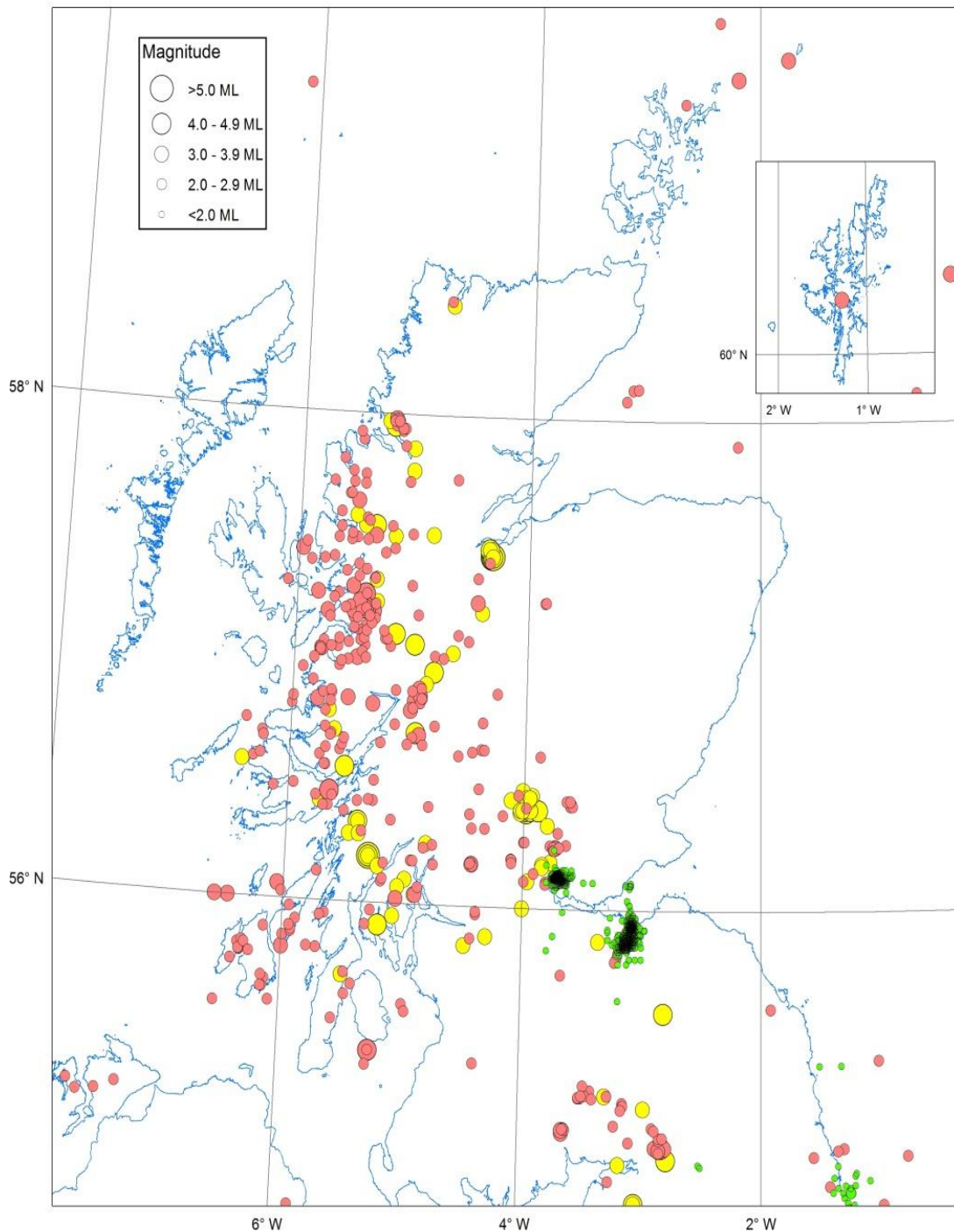


Figure 6.1. Recorded seismicity in Scotland. Instrumentally recorded earthquakes of magnitudes greater than 2 from 1970 to present are in red. The lower detection threshold of 2 reflects the fact that unless specialised networks are used, it is not possible to distinguish lower magnitude seismicity from background noise such as passing vehicles etc. Historical earthquakes of magnitudes greater than 3 from 1382 to 1970 are in yellow. Historical earthquake information is obtained from documents and reports that detail the effects of what people felt during past earthquakes. This allows locations and magnitudes to be estimated by comparing this information with similar reports for recent earthquakes. Earthquakes associated with coal mining activity with magnitudes of -1 and above are in green. The low detection thresholds for coal mining earthquakes were only possible because various temporary networks were deployed. In Scotland, these networks were mainly in Midlothian, so it is quite possible that there were small mining induced earthquakes in other coalfields, e.g. Fife, Lanark, of which the BGS have no record.

6.40 Flaring may also be a noise source (AEA, 2012a). However, increased noise is generally associated with increased gas pressure and so flaring noise associated with unconventional hydrocarbons should be less than that associated with refinery activity or gas compression facility vent relief valves. These lift as a safety mechanism when the pressure builds up.

Light pollution

6.41 Light pollution may be caused by flaring or by lighting for safe working. This is required particularly during the drilling phase, which occurs around the clock until complete. Truck movements may also contribute to light pollution. Planned flaring and truck movements could be scheduled to primarily take place during daylight hours to reduce light pollution. Spotlights that shed light only on the working area can be used to minimise light pollution.

Landscaping and Visual Impact

6.42 Features such as soil bunds (created from the excavated site soil) represent landscaping undertaken as part of site preparation. These are common to many other construction projects and is generally considered to have a low risk of intrusive visual impact (AEA, 2012a). However, the use of drilling rigs, where multiple pads are developed in a given area, is considered to have a moderate risk of significant visual effects, especially in residential areas (AEA, 2012a).

6.43 To expand, for shale gas operations, the initial drilling requires a rig with a mast typically 30 m in height. Once initial drilling is complete, this rig is replaced with a work-over rig (typically with a mast 22 m high), which remains in place for several weeks during hydraulic fracturing (Cuadrilla Resources, 2014). These rigs are temporary structures and the drillhole is then capped with an extraction point and protective cage approximately 3 m high. The extraction configuration may influence visual impact: it is not yet apparent if drilling and workover for shale gas would be on multiple individual pads (as has been established with coal bed methane at Airth) or if tens of deviated bores for shale gas would be operated from one large pad, which could be operational for 20 or 30 years.

Air emissions and air quality

6.44 Changes to air quality as a result of unconventional hydrocarbon extraction may be direct, from site emissions, or indirect as a result of a changing fuel mix.

Direct Air Emissions:

6.45 Methane and higher hydrocarbons are potent greenhouse gases (Highwood *et al*, 1999) and their release into the atmosphere is not desirable. These hydrocarbon emissions and others, such as volatile organic compounds (VOCs) and combustion products from site activities, can also impact on local air quality. In Scotland, such emissions currently occur from some landfill sites, peatlands and oil and gas processing and handling infrastructure.

6.46 Direct air emissions arising from unintentional leaks, venting and flaring are termed 'fugitive emissions'. With unconventional hydrocarbon extraction, fugitive emissions are predominantly released from flowback and produced water and leaking infrastructure. The composition of fugitive gas depends on the source geology. Coal bed methane

typically contains a higher proportion of methane than in shale gas, and fugitive emissions can contain a wide range of VOCs (Public Health England, 2013; Bunch *et al*, 2014; Zielinska *et al*, 2010).

- 6.47 If released in high concentrations (generally making up greater than 5% of the mix) in the presence of an ignition source, methane mixed with air can be flammable or explosive. Thus during hydrocarbon extraction, careful monitoring of wellhead areas with automated sensors fitted with alarms is common practice, being required by the Health and Safety Executive (HSE), since accumulation of potentially explosive mixtures of methane and air are a mortal hazard to the workforce. If substantial methane releases are detected, alarms are sounded and the site is evacuated to a muster point at a safe distance from the wellhead. Any such incident is a major setback to operations, with fugitive emissions representing a loss of valuable product. This is in addition to a duty of care to protect the workforce from hazardous working environments.
- 6.48 Unconventional gas comprises a mixture of methane and higher hydrocarbons, such as ethane and propane (e.g. in coal bed methane, Moore 2012) which are generally separated in order to isolate the methane. These fractions may be an important constituent of the Scottish unconventional shale gas reserve and, if they are of economic value, could be separated on-site or the product piped to a nearby processing plant or natural gas mains e.g. in Scotland at Grangemouth or Mossmorran. Either approach to separation presents opportunities for leakage of material to the environment and so these processes require to be monitored, especially given the uncertainty over emission levels.
- 6.49 Other gas emissions will arise through the use of vehicles and operation of equipment, such as compressor engines and on-site refining. These can emit oxides of nitrogen, which like methane and volatile organic compounds can generate ozone. Ozone is considered by the European Commission to be a 'risk of potentially high significance' due to its adverse effect on respiratory health when present at elevated concentrations (AEA, 2012a). The European Commission consider that 'emissions from numerous well developments in a local area or wider region could have a potentially significant effect on air quality' due to the cumulative effects from intensity of development (AEA, 2012a).
- 6.50 The environmental impact of planned and fugitive emissions can be reduced by appropriate technological adjustments, effective management, and by monitoring to identify when remedial action is required. Best available techniques (BAT) for reducing greenhouse gas emissions from shale gas exploration have been documented, but these have not been formally accepted by the European Commission into a BAT Reference Document (BREF) (AEA, 2012a,b). These techniques include 'Reduced Emissions Completion,' also known as 'Green Completions', and represent approaches to minimise emissions that may already have been implemented to maintain safe working practice.
- 6.51 These approaches reduce emissions in two ways:
- through capture and harvest e.g. separation of gas from high pressure flowback water in a sealed system, which should be in place in sites with good husbandry;
 - by conversion to a less potent greenhouse gas. Methane has a global warming potential 28 times greater than carbon dioxide when compared over 100 years and with no climate feedbacks (Myre *et al*. 2013). Thus flaring or a similar oxidation process to convert the methane to CO₂ reduces the global warming impact.

- 6.52 However, the need to implement this technology may be site-specific. For example, in the USA, around 87% of the natural gas wells fractured in coal bed methane formations were not considered candidates for green completions as low pressure in these systems made technological installation unnecessary (US EPA, 2012).
- 6.53 In the United States, the level of fugitive emissions from shale gas operations has been estimated to range from 0.42 - 7.9 % of total gas production (US EPA, 2013; Allen *et al*, 2013; Tollefson, 2012; Howarth *et al*, 2011). Recent airborne measurements of a methane flux from a 2800 km² area in Pennsylvania indicated that seven well pads in the drilling phase accounted for 4 - 30% of this flux. The size of the emission is 2 to 3 orders of magnitude greater than US Environmental Protection Agency estimates for this operational phase (Caulton *et al*, 2014).
- 6.54 However, the latter higher estimate of 7.9% of total production has been challenged on some of the assumptions underpinning the analysis, such as estimates that 100% of the gas is vented as opposed to flared, and green completions are not used (e.g. Cathles, *et al*, 2012, Howarth, *et al*, 2012). Such venting would not be permitted except in emergencies in the UK and high emissions associated with venting are therefore unlikely. Additionally, as gas condensate is commercially valuable, most companies would prefer to separate and sell the gas condensates than flare them, thereby reducing the total greenhouse gas emitted from any flare.
- 6.55 The contrasts in geology and source material in Scotland are such that fugitive emission profiles from the US cannot be assumed to represent the Scottish situation. Additionally, the Scottish regulatory regime that controls monitoring and imposes remedial action differs from the US (discussed further in Chapter 7). A framework for quantifying fugitive emissions and attributing source is in early stages in England (National Physical Laboratories, 2013) but does not yet exist for Scotland.

Indirect changes to air quality

- 6.56 It is difficult to say with any certainty whether extraction and exploitation of unconventional gases could result in changes to air quality on a national scale. If gas is available at sufficiently low prices, this could encourage greater uptake of gas for energy generation and domestic heating and conversion of vehicles from liquid hydrocarbons to liquid petroleum gas and electric power sources. Increased use of gas as a fuel could result in lower emissions of sulphur dioxide, oxides of nitrogen and particulate matter both from point sources (e.g. power stations) and locally (e.g. transport). Further, a reduction in atmospheric loading of air pollutants through use of unconventional hydrocarbons could represent an environmental benefit.
- 6.57 Fuel-switching could have local and transboundary impacts on air quality; however this would ultimately be dependent on costs of fuel and uptake of alternative technologies (which are not guaranteed). Also, due to the transboundary nature of air pollution, secondary PM_{2.5} produced elsewhere accounts for 30-40% of the total modelled background PM_{2.5} concentrations in Scotland (Air Quality Consultants, 2012) so it may require a European-wide conversion to reduce air pollutant concentrations.

6.58 The future scenarios for fuel-switching are uncertain and unpredictable at this time so it is not possible to quantify potential impacts on air quality (either positive or negative).

Compatibility with Scottish Government GHG reduction targets

6.59 The Climate Change (Scotland) Act 2009 has set ambitious targets for reducing greenhouse gas (GHG) emissions, with an interim 42% reduction target for 2020 and an 80% reduction target for 2050. The impact of unconventional gas extraction on meeting these targets needs to be assessed as follows:

- their overall contribution to Scottish emissions;
- the comparison of unconventional gases against other fuel types;
- the implications of developing and using unconventional gases over time.

6.60 Scottish emissions are accounted for on a national accounting basis within Europe. A robust EU Emissions Trading System, an EU emission target and an effective international agreement on capping emissions are also highly relevant to discussion of unconventional gas in this context.

6.61 The emissions from unconventional gas fall into both the traded sector and the non-traded sector. The traded sector is from large point sources and power plants of 50 MW or greater. If used in plants to generate electricity or heat, then unconventional gas will simply displace existing North Sea or imported gas, with minimal net effect.

6.62 The rate of decrease in traded sector emissions is controlled by the European emissions cap, and cannot be altered by an individual European Member States. Over-achieving by Scotland, will simply allow more emissions to be purchased in the market by a second Member State, to continue their current operations.

6.63 Emissions counted within the untraded sector include those associated with development of the site(s), operations of equipment on site, and fugitive emissions. These will all be counted into a Scottish inventory and will increase and maintain Scottish direct emissions now, and into the future, if more gas is consumed.

6.64 Unconventional hydrocarbon extraction will maintain and continue Scottish emissions above an alternative scenario of importing more gas – because ownership of all this group of emissions during extraction lies locally with the state where the extraction occurs. Importing methane gas brings less liability than home-produced gas. This is consistent with the current position on production and export of other hydrocarbons.

6.65 The effects of using unconventional gas on global emissions and atmospheric CO₂ concentration will depend on whether this gas is displacing another fuel, or whether this is an additional source. While unconventional gases used in Scotland will impact on the domestic GHG inventory, if that gas is alternatively exported, then Scotland's emissions and GHG targets will not be affected. Again this is consistent with the current position on production and export of other hydrocarbons.

- 6.66 Although subject to debate (Cathles *et al*, 2011; Howarth *et al*, 2012), current thinking is that the carbon footprint of shale gas emissions will be comparable to conventional gas sources and lower than coal if used for electricity generation (Mackay and Stone, 2013). Unabated gas emits 350 gCO₂ per kWh of electricity generated, whereas unabated “old” coal emits about 900 gCO₂ per kWh electricity generated, which is considerably more.
- 6.67 However, the position is complex. For example, as a result of the greater use of indigenous shale gas in the United States for electricity production, there has been increased use of North American coal in Europe. This has made it more economically favourable to use exported North American coal in power stations. This global energy substitution further increases the carbon footprint of coal. While the use of gas may bring a benefit through replacing coal use, there is a longer term risk that investment in gas, particularly gas power generation, will replace investment in lower-carbon renewable technologies.
- 6.68 DECC (Mackay and Stone, 2013) considers that “without global climate policies (of the sort already advocated by the UK) new fossil fuel exploitation is likely to lead to an increase in cumulative GHG emissions and the risk of climate change”. The report recommends that Government should discuss with regulators appropriate mandatory requirements to require emission reduction techniques at each stage.
- 6.69 All of these present significant challenges to the Scottish Government in ensuring management of unconventional gas production and use, remains consistent with its ambitions on climate change and specifically carbon reductions. Life cycle assessments of the carbon footprint of unconventional hydrocarbon extraction are becoming more common (e.g. Skone *et al*. 2011, Forester and Jonathon, 2012). However, these are largely from outside the UK and, given the differences in resource storage, accessibility, extraction, processing and geographical reach of infrastructure, it suggests the findings from geographically distinct areas are unlikely to be directly transferable.
- 6.70 This contrasts with surface developments, such as windfarm infrastructure, where the Scottish Government commissioned the development of a carbon calculator for payback time (Smith *et al* 2011), which is considered valuable internationally (e.g. SEIA 2011).
- 6.71 To address the lack of knowledge of the carbon footprint of the unconventional hydrocarbon industry, the Scottish Government has commissioned a desk-based study of estimated GHG emissions from exploration to the point of fuel production, which could be used to identify practises to minimise GHG emissions, such as the non-disturbance of Scotland’s precious peat resources (an important European terrestrial carbon store and on-going sink for atmospheric CO₂) (e.g. Scottish Parliament Information Centre (SPICe), 2012).
- 6.72 However, unless there is comparison of the emissions that will be saved by the change in energy generation from other fossil fuel or renewable sources, which in turn requires their complete carbon footprint to be calculated, the net loss or gain in greenhouse gas emissions that unconventional hydrocarbons will offer cannot be ascertained.

6.73 In summary on GHG:

- the decarbonisation benefits of unconventional hydrocarbons from Scotland are not clear or guaranteed;
- Scottish emissions during appraisal and production of unconventional gas may increase;
- benefits from the use of unconventional hydrocarbons in power plant for electricity generation depends on displacing coal in Scotland, which could amount to millions of tonnes CO₂ per year, but depends on many other market factors;
- benefits in use of unconventional gas in gas powered electricity are negligible;
- use in fuel switching of domestic customers from coal or oil could reduce Scottish GHG emissions by a small amount;
- continuing gas usage in domestic heat and cooking is better than unabated coal- or gas-fuelled electricity, but domestic combustion needs to be phased out on the Scottish decarbonisation pathway;
- using Scottish unconventional hydrocarbons as feedstock for petrochemicals may be the minimal GHG impact;
- additional greenhouse gases from fossil carbon will be emitted to atmosphere globally, by extraction of Scottish unconventional hydrocarbons;
- developing and operating CCS is one way to extend the lifetime of use for fossil hydrocarbons.

Baseline characterisation, post-production remediation issues and reinstatement of assets

6.74 There have been relatively few reports of groundwater contamination when compared to the vast majority of operations in North America, with many reports demonstrating that high groundwater methane levels appear to be unrelated to recent hydraulic fracturing (e.g. Molofsky *et al.* 2011). However, recent chemical and isotopic studies appear to show that, in some instances, groundwater contamination may have resulted from recent gas exploitation (Jackson *et al.* 2013).

6.75 Additional monitoring prior to and during activity could help to provide assurance over the contamination of groundwater. The frequency and density of monitoring could be guided by a number of factors including:

- the number and locations of gas extraction boreholes;
- whether fracturing is required;
- the number and proximity of sensitive receptors (water users, water features) and potential pathways (groundwater, faulting, mineworkings).

6.76 The UK Onshore Operators Group (UKOOG, the trade body for onshore oil & gas operators) has developed industry best practice guidelines for decommissioning boreholes (OGUK, 2012).

6.77 The longevity of casing and cement in abandoned boreholes must be considered, as even correctly sealed boreholes may eventually allow leakage (Miyazaki, 2009). However, this will occur only if there is a powerful hydraulic head in the aquifer, and this is unlikely in spent, unconventional hydrocarbon reservoirs with under-pressured conditions. Inspection and monitoring can also ensure that decommissioned unconventional gas boreholes and seals/plugs retain their integrity.

6.78 Other pathways for leakage may also exist, such as through faulting, mine workings or other boreholes which may be some distance from the wellhead. However, this requires artesian groundwater pressures. The likelihood of this threat could be assessed by hydrogeologists and the post-production monitoring plans could be developed, based on assessment of risk that is sensitive to hydrogeological controls.

6.79 Examples of good practice can be drawn from other industrial sectors, such as landfills and coal mining. Abandonment monitoring at surface coal mining sites generally continues for five years, extendable to ten years for higher risk sites (Younger and Sapsford 2004). The Landfill (Scotland) Regulations 2003 do not state explicitly a minimum duration for aftercare monitoring of groundwater and gas, but they do require a minimum frequency of 6 monthly monitoring. Currently there is no specific legislation for monitoring once a PEDL, CAR or PPC licence is surrendered. This regulatory gap in minimising and eliminating future environmental impact is discussed further in Chapter 7.

Risk of pollution

6.80 There may be different environmental impacts depending on whether waste mitigation is undertaken at the point of production (local containment) or at a central location (pollution may be possible *en route*, but some chemical storage would be restricted to one site). However, alongside monitoring and mitigation approaches, pollution risk can be minimised by planning to reduce the likelihood.

Societal challenges and impacts:

6.81 The social impact of development is dependent on the proximity, population density, socio-demographics and economics of the development area. As part of the consultation process, dialogue will take place between industry and local communities to discuss these social impacts. This dialogue should enable communities, operators and regulators to develop strategies to mitigate negative impacts and enhance positive impacts (Joao *et al.* 2011). The social impact can be managed to some extent by the design of the development and its operation (e.g. local procurement of labour). Issues around effective communication of risk and dialogue with affected publics are discussed further in Chapter 8.

Population growth and demographic profile

6.82 An influx of industry-related workers can have positive effects (for example, increased demand in local shops or restaurants), or negative effects (for example, increasing demand for local medical provision, or socio-demographic differences between the workforce and the local community) (Cook *et al* 2013). The consequences of rapid population growth and demographic change, both long-term and short-term, are known from examples from the extractive industry developments worldwide. For instance, a detailed study of a single county in Colorado that had experienced a 39% increase in oil and gas drilling from 2000-2007 found significant increase in demand for private and rented housing, but also increased traffic congestion, crime and drug violations (Witter *et al*, 2008).

Impact on house prices and insurance

6.83 In the US areas where shale gas has been developed, house prices have gone up as well as down (Muehlenbachs, *et al* 2014). It is too early to tell if UK/Scottish unconventional gas industry would influence house prices. UK mortgage and estate agent industry blogs report a 20 -30% drop in house prices in areas near Cuadrilla's shale gas site in the UK (Property and Land Information blog), though others state that "it is too early to tell". Other industry blogs have suggested that unconventional gas developments could open up a new buy-to-let market (Faith, 2013).

6.84 The UK Association of British Insurers has stated that damage caused by either explosion or earthquake would be covered by house insurance and that insurers do not at present perceive there to be a risk of seismic activity due to fracking that could damage properties (Insley, 2012). This is in accordance with the scientific statements on the very low likelihood of felt seismicity from fracking (Mair *et al*, 2012; Cook *et al* 2013).

Health impacts of unconventional oil & gas development

6.85 Health impacts from any new industry include occupational health issues for workers, public health impacts for local or regional populations, and the health impacts of any wider effects such as the effect of increased greenhouse gas or particulate emissions (Adgate *et al* 2014). These impacts can include:

- Known or predictable hazards for workers, the immediate local resident and transient population and the wider general population arising from technology and processes used in the exploration and exploitation phases;
- Hazards associated with the ongoing support infrastructures, waste disposal, drainage, increased transport, accidents, heavy goods traffic emissions;
- The impacts arising from climate change induced by increased atmospheric CO₂ concentrations, due to extending fossil fuel use for longer than might otherwise have occurred if zero/low carbon emission renewable sources substituted fossil fuels.

6.86 Media coverage of the possible health impacts of unconventional oil and gas developments has been increasing. Health impacts on humans (and animals) have been alleged by communities living near to shale gas and CBM sites in the USA and Australia (Adgate *et al*. 2014; Cook *et al* 2013). At the present time, many of these reports are 'anecdotal' in the sense that the observations have not been corroborated by objective study using factual evidence or properly quantified.

6.87 A second problem with many of the reported impacts is that the data gathered have not been compared against baseline statistics describing the population's health before the shale gas or CBM developments. This is partly because, in most cases, such baseline public health studies do not exist. Lack of adequate baseline data on local populations is a fundamental problem in trying to assess the evidence of adverse health impacts associated with the use of these technologies. In Scotland and the rest of the UK, this could represent an opportunity to ensure that this fundamental problem is addressed before the chance to conduct adequately robust epidemiological studies is lost (c.f. Kovats *et al*, 2014; Law *et al*, 2014).

- 6.88 Risk (in the context of the science of Risk Assessment) is described as the combination of the hazard posed by a given event and the likelihood (statistical probability) that the event will occur. For example, the risk of fracking-induced felt seismicity causing damage to properties or people at the surface is considered to be very low: very few earthquakes have been triggered by fracking for shale gas (3-5 documented cases of felt seismicity over millions of frack jobs, Davies *et al* 2013), and the *hazard* they pose is very small since the few incidences of felt seismicity were at such small magnitudes that they caused little or no environmental effect or damage to the built environment.
- 6.89 In practice, this objective approach has to be adjusted to allow for the role that public perception plays in determining the acceptability of any identified or potential “risk”. For instance public opinion surveys consistently show that shale gas extraction is “associated with” earthquakes (see Chapter 8). Equal risks in terms of probability are not perceived equally due to a host of factors (fear factors) with which the public interpret the significance personally or to their family (Health Protection Network 2008).
- 6.90 The pollution source-pathway-receptor model is the international regulatory standard paradigm to assess pollution risks (e.g. Health Protection Agency 2009). For a risk to human health to exist, it is not sufficient to have a “hazard” source alone, there must be a “source-pathway-receptor” linkage i.e. there must be a plausible means whereby humans may be exposed to the hazard in sufficient amounts to cause harm.
- 6.91 For instance a harmful substance (source/ hazard) may not represent a significant possibility (risk) of causing harm to humans (or other receptors) if:
- (i) there is no pathway (exposure route) by which receptors (humans) may encounter the substance physically; or
 - (ii) the concentration of pollutant in the environment is so low that the substance cannot be inhaled/ingested, or otherwise absorbed, in a dose large enough to cause an adverse physiological or clinical impact to humans.
- Other potential receptors include ground and surface water, protected ecological systems, and property including livestock, crops and buildings.
- 6.92 Concerns have been raised about the health effect of chemicals added to hydraulic fracturing fluids. Of 353 different chemical additives identified that have been used in fracking fluids (Colborn *et al*, 2011), the accompanying material safety data sheets (MSDS) indicate that 75% of these chemicals could have negative health effects.
- 6.93 However, in high concentrations many chemicals have adverse health effects, including everyday compounds. For example, the MSDS for sodium chloride (common salt, CAS #7647-14-5) includes serious potential health effects. These would only occur for concentrations of salt far higher than would be used in normal household or industrial food preparation: hence salt *is* a permitted substance. Thus, while some chemicals used in fracking may be potentially harmful to health if the dose to which people can be exposed is not adequately controlled, approval for use would only occur if consideration of the likely concentrations and pathways from a source to a given receptor identified an acceptable level of risk.

- 6.94 Determining whether a given hazard (source) is entirely or even partly responsible for a recorded health impact is a complex matter. Unlike communicable disease, where a specific organism causes a specific health impact (e.g. *Salmonella* and the predominantly gastro-intestinal illness salmonellosis), Environmentally Associated Disease (EAD) is rarely a case of “single hazard - single impact”. In general, environmental factors are one of several factors that interact to determine the probability of developing a clinical illness.
- 6.95 Societal factors may act as confounding factors that skew the data on health impacts and make it difficult to determine the attributable fraction of EAD actually associated with any specific environmental hazard. For instance changes in cancer rates and mortality, low birth weight and chronic obstructive pulmonary disease were health problems found in regions of shale gas extraction (Witter *et al*, 2008). However it was recognised that the lack of good public health baseline data for the local population, and subsequent on-going monitoring, made it difficult to be certain of the cause.
- 6.96 Further, social effects, such as the influx of predominantly male drilling workers (a gender more prone to heart disease), could have confounding effects on public health observations of increased heart disease in a shale gas region. Thus, assessing the degree of change associated with the industry is subject to major uncertainties (Adgate *et al*, 2014).
- 6.97 It appears that for communities near unconventional oil and gas development sites, the main health impact “stressors” (i.e. areas of perceived concern, even if unproven) are “air pollutants, ground and surface water contamination, truck traffic and noise pollution, accidents and malfunctions and psychosocial stress associated with community change” (Adgate *et al*, 2014). Despite these broad public concerns, no comprehensive population based studies of the public health effects of unconventional hydrocarbon operations currently exist (Adgate *et al*, 2014).
- 6.98 Whilst a draft report by Public Health England (2013) considers that “currently available evidence indicates that potential risks to public health from ... shale gas operations are low if the operations are properly run and regulated”, the case studies discussed earlier indicate that careful thought needs to be given to epidemiological assessments to allow direct risk to be assessed and so mitigated.

Conclusions

- 6.99 Although there are potential threats to the environment and the individual from unconventional hydrocarbon extraction, there are considerable legislative safeguards to ensure these threats are not realised. There has, however, to be recognition that the unexpected can happen. Some examples of best practice in addressing these challenges have environmental and health and safety legislation as a primary driver; others are being refined as the industry matures. Thus mitigating a potential or realised impact depends on strong and visionary environmental, and health and safety, regulators to enforce legislation and identify and respond rapidly to gaps that may emerge.

6.100 The impact on the Scottish Government policy for reducing GHG emissions needs strategic consideration as unconventional hydrocarbon extraction will maintain and continue Scottish fossil fuel-derived GHG emissions above an alternative scenario of reliance on renewable energy (noting our remit here is not to consider the feasibility of renewable sources in meeting complex energy demands).

6.101 The development of any new industry will potentially impact society. It is clear that detecting and alleviating negative impacts, and enhancing positive impacts, is complicated unless careful planning of how to identify impact is undertaken. Without such understanding, whether the negative impacts are acceptable outcomes of industrial development that offers intrinsic positive impacts, cannot be considered.

Introduction

7.1 There are a number of regulators and permissioning frameworks that have a role in permitting, assessing and managing on-shore hydrocarbon activities, including those termed as unconventional gas. This chapter describes those regulatory bodies and their roles and tools that are applicable to Scotland.

Regulation Landscape - European Context

7.2 On 22 January 2014, the European Commission announced a recommendation on minimum principles for the exploration and production of hydrocarbons using high volume hydraulic fracturing (European Commission, 2014). The minimum principles aim to address environmental and health concerns and the regulatory gaps identified in a series of studies undertaken by the European Commission and during stakeholder consultation (Philippe and Partners, 2011; AEA, 2012a; AEA 2012b; European Commission, 2012; European Commission, 2013).

7.3 The non-binding criteria are designed to build on and complement the existing EU environmental legislation and should be implemented by Member States within six months of the announcement. The recommendation invites Member States to:

- **Plan ahead** of developments and evaluate possible cumulative effects before granting licences;
- **Carefully assess** environmental impacts and risks;
- Ensure that the **integrity** of the well is up to best practice standards;
- **Check the quality of the local water, air, soil** before operations start, in order to monitor any changes and deal with emerging risks;
- **Control air emissions**, including greenhouse gas emissions, by capturing the gases;
- **Inform the public** about chemicals used in individual wells, and
- Ensure that operators apply **best practices** throughout the project.

7.4 The Commission plans to review the effectiveness of the recommendation in July 2015. This review will not only assess the application of the recommendation, but will consider the application of the relevant Best Available Techniques (BAT) reference documents (also known as BREF Documents) and the progress of the BAT information exchange. The Commission will further decide whether it is necessary to put forward legislative proposals with legally-binding provisions, such as a new directive to set a regulatory framework for shale gas extraction using hydraulic fracturing.

7.5 The Commission has focused on shale gas extraction using fracturing techniques. Although these recommendations and principles do not directly apply to other unconventional gas, where similar activities such as CBM are being carried out, the recommendations and principles would appear to be transferable.

European Directives of relevance to unconventional oil & gas

7.6 The directives of relevance to unconventional gas activities, using fracturing, as identified by the European Commission (AEA, 2012a) are given below. Some directives are relevant for all phases whereas others are only relevant for certain stages. It is also worth noting that some directives may not apply if fracturing is not undertaken and the Commission have not completed a similar assessment for non-fractured unconventional gas activities:

- Strategic Environmental Impact Assessment Directive (2001/42/EC) (relating to plans and programmes only);
- Environmental Impact Assessment Directive (2011/92/EU) ;
- Integrated Pollution and Prevention Control - Directive (2008/1/EC);
- Industrial Emissions Directive (2010/75/EC);
- Mining Waste Directive(2006/21/EC);
- Environmental Liability Directive (2004/35/EC);
- Waste Framework Directive (2008/98/EC);
- Water Framework Directive (2000/60/EC);
- Groundwater Directive (2006/118/EC);
- Noise Directive (2002/49/EC);
- Air Quality Directive (2008/50/EC);
- Habitats Directive (1992/43/EEC);
- Birds Directive(2009/147/EC);
- REACH (Regulation 1907/2006/ EC);
- Biocidal Products Directive (98/8/EC);
- Authorization (for the prospection, exploration and production) of hydrocarbons Directive (94/22/EC);
- SEVESO II Directive (1996/82/EC);
- 1992/29/Euratom Directive;
- Urban wastewater Directive (97/271/EEC).

Scottish Regulatory Framework

7.7 The flow chart in Figure 7.1 indicates the regulatory bodies that have a role in regulating unconventional gas exploration operations in Scotland. It is worth noting that environmental permits can be sought at any point in the process, but all permissions need to be met before any activity can commence.

7.8 The remits of relevant government and regulatory bodies are given below.

Office of Unconventional Gas and Oil

7.9 The Office of Unconventional Gas and Oil (OUGO) established in March 2013 aims to: “promote the safe, responsible, and environmentally sound recovery of the UK’s unconventional reserves of gas and oil... The Government wants to see any growth potential realised, to enhance our energy security where possible, and to safeguard the environment and public safety in the process.”

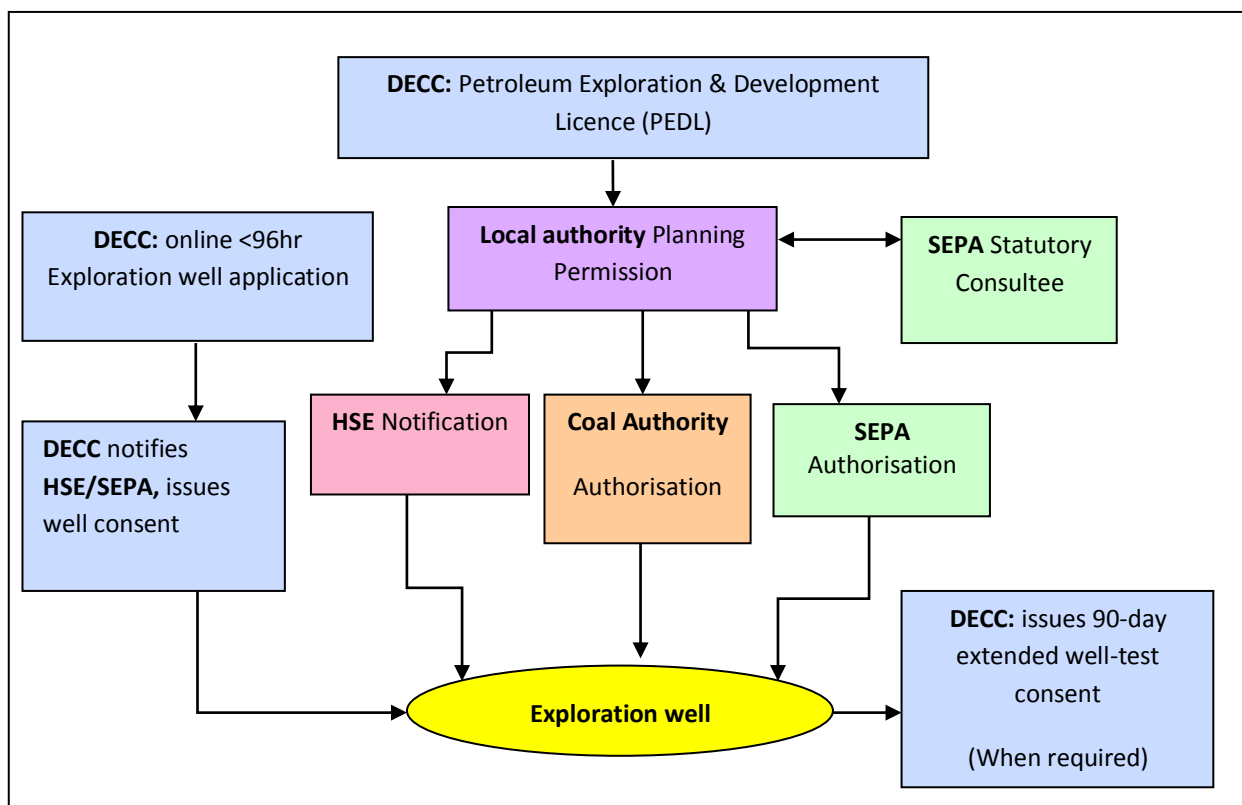


Figure 7.1. Public authorities involved in regulating unconventional gas.

7.10 OUGO published a Regulatory Road Map (DECC, 2013) for the exploration of unconventional gas in December 2013, which identified that, although energy is a reserved matter, environmental controls and planning are devolved. This roadmap provides the legislative frameworks specific to the different countries in the UK and identifies required actions and best practices at various stages

Department of Energy and Climate Change (DECC)

7.11 Oil and gas licensing in England, Wales and Scotland is governed by the Petroleum Act 1998, the Petroleum (Production) (Landward Areas) Regulations 1995, and the Hydrocarbon Licensing Directive Regulations 1995. The 1998 Act vests all rights and ownership of petroleum resources (oil and gas) in the UK government, which then grants a Petroleum Exploration and Development Licence (PEDL) in competitive licensing rounds for the exclusive exploration, development, production and abandonment of hydrocarbons in the licence area. Licences are not specific to a hydrocarbon, e.g. shale gas or coal bed methane, so apply to both conventional and unconventional extraction.

7.12 DECC assesses the licence applicant on technical competence, environmental awareness, financial viability and capacity.

7.13 Once granted, the PEDL holder must obtain all necessary drilling/development consents, planning permissions, health and safety, and environmental permits before commencing. Consent of individual landowners will also be required, although a ruling by the UK Supreme Court has confirmed that where a landowner “unreasonably refuses to agree access, where he demands unreasonable terms, or where the fragmentation of land ownership means a

licensee cannot agree terms with everyone” then the Mines (Working Facilities and Support) Act 1996, as modified by the Petroleum Act 1998, can be used in order for the licensee to obtain access rights (House of Commons, 2011). However, the UK Government has recently launched a consultation on proposals to allow onshore oil and gas operators statutory rights of access to land at depths greater than 300 m (DECC, 2014).

7.14 As described earlier in this report, DECC have implemented a traffic light monitoring system for seismicity that operators must follow. This control requires operators to monitor seismic activity in real time and stipulates action the operator must take in response to the seismic activity recorded:

- if no seismic activity is detected (green) injection can go ahead as planned;
- if seismicity of up to $0.5M_L$ is detected injection can proceed with caution, possibly at reduced rates and monitoring is intensified (amber);
- if seismicity above $0.5M_L$ is detected, injection is suspended immediately (red).

7.15 An alternative proposal (Westaway and Younger, 2014) has been made suggesting that the existing regulatory limits applicable to quarry blasting (i.e. peak ground velocities (PGV) in the seismic wavefield incident on any residential property of 10 mm per second during the working day, 2 mm per second at night, and 4.5 mm per second at other times) can be readily applied to cover such induced seismicity. Levels of vibration of this order do not constitute a hazard as they are similar in magnitude to the ‘nuisance’ vibrations that may be caused by activities such as slamming doors, or by large vehicles moving close to a building.

7.16 DECC has consulted on a Strategic Environmental Assessment (SEA) for the 14th Round of Onshore Licensing, and in December 2013 consulted on an Environmental Report which outlined the likely significant environmental effects (and other environmental effects with the potential to be significant) of further onshore oil and gas licensing. Once the consultation responses have been taken into account the UK Government will issue a “Post-Adoption Statement”, summarising how it intends to proceed in relation to further onshore licensing. (DECC, 2014)

Local Planning Authorities

7.17 Following the granting of a PEDL, the operator is still required to obtain all relevant planning permissions before exploration can commence. The Town and Country Planning (Scotland) Act 1997 as amended by the Planning etc. (Scotland) Act 2006, states planning permission is required for the carrying out of any development of land.

7.18 ‘Development’ includes the carrying out of building, engineering, mining or other operations in, on, over or under land. Full planning permission is to be considered and granted separately for each of the exploration, appraisal and production phases. Any requirements relating to local amenity, such as noise and lighting, will be covered by the inclusion of specific conditions within the planning permission.

7.19 As part of the planning permission process, the planning authority must determine if an Environmental Impact Assessment (EIA) is required. The Town & Country Planning (Environmental Impact Assessment) (Scotland) Regulations 2011 require an EIA to be

carried out for all developments in Schedule 1 of the Regulations and certain developments under Schedule 2 of the Regulations. Further guidance on EIA procedures is contained in the Scottish Government's planning Circular 3/2011 (Scottish Government, 2011).

7.20 The Management of Extractive Waste (Scotland) Regulations 2010 state that all planning applications involving extractive waste must be accompanied by a waste management plan. The waste management plan should include measures to prevent or minimise all extractive waste. This may include drill cuttings, drilling muds, waste gas and flowback and produced water returned to the surface. In Scotland, the Local Authority is responsible for implementing these regulations.

7.21 The Local Air Quality Management regime requires Local Authorities to review and assess local air quality in their area to determine whether the objectives and standards set out in the National Air Quality Strategy (DEFRA, 2007) are being met, or are likely to be met. Pollutants with objectives provided by the National Air Quality Strategy include benzene, 1,3-butadiene, carbon monoxide, lead, nitrogen dioxide, PM10, PM2.5, polycyclic aromatic hydrocarbons (PAH), ozone and sulphur dioxide.

7.22 However it should be noted that Local Authorities may not necessarily monitor for all of these pollutants. For example, ozone and PAHs are monitored at a national level. Other air pollutants relating to unconventional gas activities which are not included in the strategy are methane, higher hydrocarbons and some volatile organic compounds.

The Coal Authority

7.23 The Coal Authority regulates access to, intersection and disturbance of Scotland's coal.

Scottish Environment Protection Agency

7.24 The regulatory role of the Scottish Environment Protection Agency (SEPA) is to protect the environment and human health. This role in relation to unconventional oil and gas exploration and production is summarised in SEPA's guidance (SEPA, 2012).

7.25 Through the Water Environment (Controlled Activities) (Scotland) Regulations 2011 (CAR), the operator requires an appropriate authorisation for specific activities with the aim of preventing significant adverse impacts on the water environment. The following activities all require CAR authorisation:

- the construction of the borehole;
- the discharge of fracturing fluid to ground or surface water, including assessing hazards presented by fracturing fluids on a case-by-case basis;
- ground or surface water abstractions.

7.26 Where the Pollution Prevention and Control (Scotland) Regulations 2012 (PPC 2012) apply, for example a refining activity (Listed activity 1.2a), SEPA will require the operator to effectively manage risks to air quality, land and surface and ground water resources. SEPA's

objective is to provide a robust regulatory framework and SEPA is currently in discussions with Scottish Government to clarify aspects of the role of the PPC regime.

7.27 SEPA is responsible for regulating the management of wastes that contain naturally occurring radioactive materials (NORM). Regulatory controls in respect of the radioactive content of waste are not required if the operator generating such wastes (e.g. waste waters, sediments and scales) can demonstrate that the NORM is below threshold levels set by the Radioactive Substances Act 1993 (RSA 93).

7.28 If concentrations of NORM are above the threshold levels in RSA 93, the management of NORM containing wastes, including their disposal to the environment, is regulated by SEPA. SEPA will impose conditions that require the operator to treat and dispose NORM in a manner that minimises the impact on the public and environment. The treatment and disposal options available to the operator will be specific to the degree and type of contamination and will be assessed and controlled by SEPA on a site-specific basis. Any storage that is necessary prior to treatment or disposal is also regulated by SEPA under RSA 93.

7.29 Other controls imposed by SEPA are:

- to ensure the appropriate treatment and disposal of waste produced during exploration, appraisal and production;
- to be a statutory consultee in the planning and Environmental Impact Assessment process and provide advice to local authorities on individual gas extraction sites;
- to enforce the Environmental Liability (Scotland) Regulations 2009, if applicable, which requires operators to take remedial measures where there is an imminent threat of environmental damage or their activities have caused environmental damage;
- to enforce the Control of Major Accident Hazards Regulations 1999 (COMAH), where applicable, alongside the Health and Safety Executive;
- to enforce the Water Environment (Oil Storage) (Scotland) Regulations 2006, where applicable.

Health and Safety Executive

7.30 The Health and Safety Executive (HSE) is the regulatory body responsible for regulating the safety of workers, for example during drilling operations. The primary regulatory tools include:

- The Borehole Site and Operations Regulations 1995;
- The Offshore Installation and Wells (Design & Construction etc.) Regulations 1996;
- The Health and Safety at Work etc Act 1974 is focused on general occupational health, including workers being exposed to noise and safe lighting when working out-with daylight hours;
- The Control of Major Accident Hazards Regulations 1999 (as amended) (joint competent authority with SEPA);
- Pipelines Safety Regulations 1996 (where required).

Marine Scotland

7.31 Marine Scotland is responsible for marine issues around Scotland, including marine planning. However, matters relating to oil and gas licencing are reserved to Westminster (DECC). Marine planning matters in Scotland's inshore waters, i.e. up to 12 miles, are governed by the Marine (Scotland) Act 2010, an Act of the Scottish Parliament, and in its offshore waters by the Marine and Coastal Access Act 2009, an Act of the UK Parliament.

7.32 Through these Acts, the National Marine Plan is currently being produced (and consulted on) which sets out the strategic policies for the use of Scotland's marine resources. Marine Scotland and other public bodies, such as the Local Authority, will take authorisation decisions in accordance with the National Marine Plan. The National Marine Plan includes a section on Oil and Gas.

Other Parties of Note

Scottish Government

7.33 The Scottish Government's current position on unconventional oil & gas is set out in Scottish Planning Policy (Scottish Government, 2010) and the Draft Electricity Generation Policy Statement (Scottish Government, 2012). The Scottish Government announced that it plans to strengthen Scottish Planning Policy relating to onshore unconventional oil and gas (Scottish Government, 2013), as follows:

"The new Scottish Planning Policy, which comes into force next year, will reinforce environmental and community protection and community consultation guidance in relation to planning applications for unconventional gas extraction. It also introduces the need for buffer zones in relation to such planning applications. Amongst the changes to the policy it states that the planning system must 'minimise the impacts of extraction on local communities, built and natural heritage, and the water environment'".

British Geological Survey (BGS)

7.34 The BGS is not a regulatory body, but requests notification of intent to construct new wells and boreholes. There is also a legal duty on all drilling operators to pass to BGS information on all boreholes drilled to depths greater than 30 m for mineral exploration and 15 m for water supply assessment (BGS, 2014).

Potential Regulatory Gaps

7.35 In 2012, a report for the European Commission report (AEA, 2012a) highlighted a number of regulatory gaps, uncertainties and issues. The Commission's 2013 Work Programme included further Member State engagement and the completion of an Impact Assessment to further clarify the European regulatory framework.

- 7.36 The Impact Assessment included options on possible legislative frameworks, ranging from doing nothing, to issuing guidance on the application of existing relevant directives (which was the favoured option of the UK government), to developing a tailor-made directive (European Commission, 2014). The outcome was that the Commission proposed a number of recommendations and principles for member states to meet.
- 7.37 A detailed assessment of the recommendation and principles outlined by the Commission (European Commission 2014), has not been carried out by the Expert Scientific Panel.
- 7.38 In Scotland, the Pollution Prevention and Control (Scotland) 2012 Regulations (PPC) apply where an activity named in Schedule 1 of those regulations, such as refining, is carried out. However, typically these activities are not carried out during the exploration or appraisal phase.
- 7.39 Currently, where a PPC activity is being carried out, any flaring and venting being proposed within the PPC permit boundary will be regulated as being directly associated. However if there is no PPC activity being carried out then any flaring occurring cannot be regulated under PPC, as it is not in itself a named activity. This differs to the Environmental Permitting Regime in England and Wales where some flaring and venting is regulated.
- 7.40 The Management of Extractive Waste (Scotland) 2010 Regulations, enforced by the planning authority, may include a requirement for waste gases (e.g. fugitive methane emissions) to be managed, however these may not always be engaged. Where neither a PPC named activity nor an extractive waste activity are being carried out, fugitive emissions at any treatment facility or wellheads may not be regulated.
- 7.41 There is debate whether source magnitude used in DECC's traffic light system for seismicity is the best measure when considering seismicity limits (Westaway and Younger, 2014). Surface velocities may provide a better indicator of surface damage and would not penalise unconventional gas operations relative to quarrying, which is already regulated for vibration on surface velocity, not local magnitude.
- 7.42 Post-production long-term monitoring and responsibility is another potential gap. Once the operator has surrendered the CAR authorisation and met HSE well-abandonment requirements and, later, when the PEDL post production requirements have ceased, there are no long-term monitoring and control requirements to ensure that well integrity is retained and pollution is not occurring. However, operators have an open-ended liability to remediate any ineffective abandonment.
- 7.43 A proposed clause (clause 35) to the Water Bill requiring 'onshore oil and gas operators to provide financial security when applying for an environmental permit so that funds would be available to deal with any water pollution incident caused by the operator' has not been supported by the UK Government. The UK Government believes that the existing regulatory framework is fit for purpose for the exploration and exploitation of onshore oil

and gas and no further controls are required. This could lead to uncertainty with regards to responsibility for remediation if the operator goes bankrupt.

7.44 A review of 35 Environmental Statements (ES) prepared within the offshore oil and gas industry in conjunction with interviews with regulators, operators, consultants and advisory bodies found a mixed picture of EIA performance. The main findings were:

- a significant number of ESs fell short of satisfactory quality;
- the process appeared to be driven by compliance rather than best practice (Barker and Jones, 2013).

7.45 An earlier review of EIAs conducted in the Scottish forestry industry (Gray and Edwards-Jones, 1999) found instances of good practice in the assessment process, but overall poor quality of EIA and ES production.

7.46 The recurring elemental failure, which subsequently led to additional difficulties, was the absence of a full scoping phase. Thus, assessments were unfocused, did not adequately investigate the key issues and wasted effort on irrelevancies. This resulted in inadequate baseline data collection, and made the task of assessing the magnitude and significance of impact extremely difficult (Gray and Edwards-Jones, 1999).

7.47 Further, the current EIA methods can take little account of the socio-economic impacts of pollution (e.g. Jarvis and Younger, 2000), with predictive EIA strategies for future discharges lacking, and a sense that the water environment and groundwater may be under-considered (e.g., Kuma *et al*, 2002).

7.48 Baseline measurements need to accommodate natural temporal variability and other ES findings could inform future EIAs. Developments to ensure excellence in the EIA could be undertaken using identifiable protocols shaped by stakeholder feedback, in addition to statutory requirements. Additionally, in the UK there is no mandatory review stage in the assessment process (Gray and Edwards-Jones, 1999), although this is being reconsidered as part of the EIA directive review (European Commission, 2013). Incorporating this may support the development of excellent ES.

Conclusions

- A regulatory framework already exists in Scotland, which covers the vast majority of activities requiring control and monitoring as part of unconventional oil & gas developments. This is generally well-coordinated between the main regulatory bodies (DECC, HSE, Local Authorities, SEPA, the Coal Authority).
- The recommendation and principles outlined by the Commission (European Commission 2014), have not been reviewed by the Expert Scientific Panel;
- Where an activity named in Schedule 1 of Pollution Prevention and Control (Scotland) 2012 Regulations (PPC) regulations, such as refining, is not carried out, typically during the exploration or appraisal phase, then there may be a gap in regulation. This applies particularly, but not exclusively, to flaring and venting;

- The Management of Extractive Waste (Scotland) 2010 Regulations (MEW), enforced by the planning authority, may include a requirement for waste gases (e.g. fugitive methane emissions) to be managed; however these may not always be engaged. Where neither a PPC named activity nor an extractive waste activity is being carried out, fugitive emissions at any treatment facility or wellheads may not be regulated;
- Where neither PPC nor MEW applies there will be a gap in the regulation of monitoring and management of air quality within the gas extraction site;
- Post-production long term monitoring and responsibility is another potential gap;
- It is recognised that the Environmental Statement and the EIA process, when applied to unconventional gas development, must be comprehensive with total awareness of all possible short and long-term, local and regional impacts.

Public reactions to unconventional gas to date in the UK

- 8.1 Before 2011, the subject of unconventional oil & gas was not routinely reported or debated in the national media. However, the induced seismic events at Preese Hall in 2011 and the subsequent UK Government moratorium on hydraulic fracturing (fracking) for shale gas brought the issue into the public consciousness. From that point onwards, unconventional oil & gas has featured frequently in the media.
- 8.2 The UK Government has also outlined a supportive policy towards shale gas development in particular, with a number of highly publicised announcements.
- 8.3 At the same time, campaigns and protests against unconventional gas (in particular where fracking is involved) escalated in the UK. For example, in August 2013, Cuadrilla had to scale back exploration activities in Balcombe, Sussex, in part due to active public resistance. It is worth noting that, contrary to many protestors' concerns, the hydrocarbon exploration being proposed at Balcombe was not for shale gas and would not have involved hydraulic fracturing. Anti-fracking campaigns have also focused on CBM activities, e.g. those organised by Frackfree Scotland, Frack off Scotland and Frack Free Forth Valley, Concerned Communities of Falkirk, Canonbie Residents against Coal and Friends of Earth Scotland.
- 8.4 Robust, scientific evidence around the safety and regulation of unconventional oil & gas is becoming available. However, as in any emerging field of research, evidence is sometimes conflicting or appears to be contradictory. In addition, outcomes from research that is either untested, or has not been subject to peer-review has been cited in the media and circulated on the web.
- 8.5 Evidence from active shale gas and CBM sites comes particularly from the USA and Australia. Caution is required when trying to extrapolate evidence because these developments occur under very different regulatory and economic conditions than are likely in the UK. Therefore, conclusions drawn from these studies should only be applied to the UK or Scotland very carefully.
- 8.6 Expert, political and media discussion tends to imply that the public are lacking knowledge about the risks associated with unconventional gas, and need to be informed (e.g. article in *The Telegraph* from Dominiczak, 2014). The public also expresses many concerns that are not just questions of safety, including questions around trust in, and the motives of, policy makers and operators, human-environmental ethics and social justice (Williams, 2013; Jaspal *et al* in press).
- 8.7 It is understandable that there is confusion and uncertainty among the general public and there is an urgent need to understand and address the genuine concerns that communities have about unconventional gas. Confusion has been expressed about the

regulatory framework and a lack of confidence in the regulatory regime. Commonly expressed concerns include:

- *Environmental concerns (water contamination, air pollution, naturally occurring radioactive substances);*
- *Water consumption;*
- *Induced seismicity (almost uniquely in the UK);*
- *Effects of a new fossil fuel resource on climate change targets;*
- Reconciling investment in unconventional gas with investment in renewable energy;
- Social impacts (e.g. social impact of staffing accommodation, truck movements, noise, visual impact);
- Health concerns (for example, exposure to carcinogens or air pollutants);
- Industrialisation of rural landscapes and effect on food production;
- Corporate and government power and trust;
- Community disempowerment (e.g. lack of consultation, uninvited respondents to public demonstrations).

8.8 The dominance of risk assessment approaches in the science and technology reports on unconventional gas (italicised in the list above) means that much of the public concern is “framed out” of such debates. Public engagement is often framed as informing the public and smoothing the path to a new industry: “the *public reaction* to the earthquakes, rather than the earthquakes themselves, is said to undermine fracking” (Jaspal and Nerlich 2014). Genuine public engagement on unconventional gas needs to include a consideration of social, political and ethical aspects of developments, both within the community and as a nation.

8.9 Media representation of the debate can be defined broadly into two camps (Jaspal and Nerlich 2014). There is a body of media that focuses on the negative environmental and health effects of unconventional gas, and which places the burden of proof on operators and policymakers/regulators to proceed safely (the precautionary principle). A second body of media focuses on the potential of unconventional gas to increase the indigenous (UK) energy resource, lower prices and create jobs, and which emphasises that gas is a greener supplier of baseload electricity than coal. The latter point of view emphasises that, as long as best practice is implemented, the best way to exploit these resources is “learning by doing” (Williams 2013).

8.10 Such polarised views often result in the “cherry picking” of data and anecdotal evidence to support either position (Jaspal and Nerlich 2014), making it a harder proposition to use the wider body of robust evidence to have a balanced debate on the subject. Arguably, this only leads to further confusion among the public.

Studies on public awareness and acceptability of shale gas in the UK

8.11 Detailed research by social scientists into public perceptions of unconventional oil and gas extraction is in its infancy. While there is a lot of research taking place, much of it has yet to be published in peer reviewed journals.

8.12 The DECC public attitudes tracker first asked the public about shale gas in the 2012 survey (DECC 2012). Overall, awareness of shale gas is increasing (75% to some degree

aware of hydraulic fracturing for shale gas in March 2014, compared to 42% in June 2012). In March 2014, results showed that 29% supported extraction of shale gas and 22% opposed, compared to 27% for and 21% opposed in Dec 2013.

- 8.13 In 2012, the UK Energy Research Centre commissioned research into the kind of information sources that are typically used by the public to learn about debates into energy and climate security (Happer *et al.* 2012). The primary aim was to look at how these information sources affect the formation of public beliefs and commitments to behavioural change. In follow up interviews, participants were asked specifically about shale gas and fracking. The term was familiar to few participants, and none of those fully understood the process and its environmental impacts. The researchers noted that, at this stage of learning, people are still forming their opinions and so they are more open to information and expertise on the subject. This is when the messages being portrayed by policymakers, scientists and journalists are most influential.
- 8.14 Cuadrilla Ltd commissioned a survey in October 2012 from a private survey company on public opinions in the area around Cuadrilla's licence blocks in Lancashire (Britain Thinks 2012). Survey results showed relatively low levels of knowledge about shale gas compared to other energy sources, concerns about seismicity and water contamination, and a view that shale gas could bring cheaper energy and jobs. 44% of respondents "strongly supported" or "supported" continued exploration whereas 23% of respondents said they "strongly opposed" or "opposed" continued exploration.
- 8.15 The University of Nottingham conducted eight surveys via YouGov from March 2012 to Jan 2014 with over 25,000 participants. The results suggested that public awareness of fracking had increased: the percentage of people able to identify shale gas from an opening question about hydraulic fracturing had risen from 37.6% (March 2012) to just under 66% (Jan 2014). The number associating shale gas with water contamination had fluctuated between 35% and 45%. It was found that more people associate shale gas with cheap energy (40-55%) and clean energy (36-45%) than either do not associate or don't know. In June 2012 the question "should shale gas be allowed in the UK" was asked for the first time: the percentage agreeing has remained fairly consistent at 53 - 58%.
- 8.16 An ICM (2013) Research survey commissioned by the Guardian (conducted by telephone) to over 1000 respondents in August 2013 showed that 44% of respondents agreed that fracking should take place in the UK, whereas 30% disagreed and 26% remained undecided. However, when asked whether they support fracking in their local area, the respondents displayed a split opinion, with 41% in favour and 40% opposed.
- 8.17 Researchers at the Durham University-led ReFINE group (Researching Fracking IN Europe) held a series of deliberative focus groups in March 2013 at various locations in England (Williams, 2013). The research aimed to elicit and articulate lay judgements on the exploitation of shale gas (in particular, where fracking would be used) and the underlying factors driving them. The results have not yet been published in a peer-reviewed journal but the thesis is available online (Williams, 2013).

8.18 An investigation of public attitudes by the Understanding Risk Research Group at Cardiff University suggested that the public do not see shale gas as the solution to UK energy security or reducing carbon emissions. Their research also shows that traditional risk assessments often overlook factors influencing public concerns – such as whether the risk is perceived as controllable, the amount of trust in risk management, and the effect of media reporting. Therefore “focusing on the engineering concepts of risk, such as probabilities and damage estimates, is unlikely to meet people’s actual concerns about fracking” (Economic and Social Research Council, 2012).

Tools for engaging the public

8.19 *Planning consultation.* There is a growing body of evidence showing that sustained and meaningful community engagement has beneficial outcomes for the communities, operators and policymakers (c.f. new requirements for early consultation on wind energy developments; Walker and Devine-Wright 2008).

8.20 A mitigation and enhancement plan is of most value if mitigation and enhancement are *designed into* a project. Therefore, early consultation is crucial. There are several routes for the public to engage in the planning of unconventional gas developments in their area. This list has been adapted from the UK Onshore Oil and Gas Operators Group’s guidelines (UKOOG, 2014) with reference to Scottish legislative framework and planning rules:

- (i) **Pre-Application Consultation** with local communities is part of UKOOG’s community engagement charter. This can take place via public exhibitions, face to face meetings, websites, press releases and letters. There is a legal requirement for developers to consult communities on applications for national and major developments. National developments are set out in the National Planning Framework and major developments defined in legislation i.e. anything in Schedule 1 of the EIA regulations or over 2 hectares for minerals. There is a minimum 12 week period between the submission of the proposal of application notice and submitting the application;
- (ii) **Environmental Risk Assessment (ERA)** reviews all the safety and environmental risks, and documents how these will be managed and mitigated. Operators should engage with local communities on the ERA as part of their pre-application consultation. DEFRA’s Guidelines for Environmental Risk Assessment and Management (DEFRA, 2011) suggest that a participatory risk assessment should be used;
- (iii) **Pre-planning notices.** Twenty-one days prior to submitting a planning application the operator must inform landowners of their intention to submit a planning application (and include an address for comments) by writing to landowners, displaying notices in the local area and in the local newspapers;
- (iv) **Planning Authority Consultation. Once the application has been validated by the local authority, they will conduct a public consultation over a minimum of 21-days .** This consultation is longer with Statutory Consultees (from EIA regulations). If an EIA is required/submitted then the consultation is a minimum of 28 days. If new information is provided by consultants or the public, then a further 28 day consultation period is required;
- (v) **Environmental Impact Assessment (EIA).** An EIA assesses the significance of potential environmental affects and identifies mitigation measures. The UKOOG community charter has committed operators to carrying out an EIA for all hydraulically-fractured

wells. The scoping stage of an EIA can scope in risks that are not just environmental, e.g. road traffic accidents;

(vi) **Environmental Permits from the Scottish Environment Protection Agency.** Where a license is required for the abstraction from or discharge to the water environment, SEPA will normally only require applications to be advertised where the proposed controlled activity is likely to have a 'significant adverse impact on the water environment'.

8.21 It is clear that there is scope for good practice to be conducted in community engagement at the stage of being granted an exploration licence. However, concerns have been raised that there may be a loophole when an appraisal or production licence is being granted. For example, the guidelines on ERA for exploration explicitly state that scale-up is not to be considered, which leads to a concern that if there is no ERA at the production planning stage, then there is a possibility that the next step in scale-up to exploration may be too incremental to require an ERA - thereby bypassing the need for an ERA.

8.22 *Social Impacts Assessment (SIA)* is about the process of managing the social issues associated with developments (Esteves *et al* 2012). A SIA should be a participatory process that includes facilitating community discussions about acceptability of likely benefits, forecasting likely changes from well-defined baseline data, identifying ways of mitigating potential impacts and maximising potential benefits, and negotiating between the communities and the developer/operator. While not currently mandatory, increasingly SIA is used as a tool.

8.23 *Health Impacts Assessment (HIA)* provide baseline indicators for public health and may identify any likely pathways for health impacts and suggest plans for mitigation strategies. Public health impact assessment includes social determinants for health, such as anxiety, inequality (the health status of a community is strongly determined by socioeconomic status) and green spaces.

8.24 The Public Health England report (2013, draft for comment, final version not yet published) suggests that health impact assessments are best made at a strategic level or for large scale projects as they can be time-consuming (months to years) and costly.

8.25 Social and health impacts could be scoped in to an environmental impact assessment. For instance, council planning permission could advocate for HIA to be included. Many major oil companies conduct what is referred to as an ESHIA (Environmental, Social and Health Impacts Assessment) as a matter of course.

Good neighbour agreements/Impacts benefit agreements

8.26 Good Neighbour Agreements (GNAs, e.g. Illsley 2002) are negotiated agreements between a developer/operator and a local community, where a company agrees to comply with environmental and social standards higher than those imposed by law. Friends of the Earth Scotland conducted a study in 2004, concluding that GNAs are suitable for implementation under the Scottish legal, social and political landscape (Friends of the Earth Scotland, 2004).

8.27 Impact Benefits Agreements (IBAs, e.g. O'Faircheallaigh 1999) are a very similar tool that have been used extensively in projects worldwide. IBAs build on SIA and EIA to develop

tangible benefits for local communities, and have become particularly used by indigenous communities.

Baseline data, monitoring and systems for reacting to monitoring data.

- 8.28 Many of the contentious issues in the US could have been mitigated to some degree by baseline monitoring prior to development. For instance, it is now widely acknowledged that the infamous occurrence of “flaming tapwater” in the United States, as shown in the documentary movie “Gasland”, actually pre-dated any drilling activity. Similarly, the lack of good data on public health prior to the start of drilling activities has confounded attempts to quantify and attribute health effects around unconventional gas developments in the US and Australia. Baseline data would have provided evidence of, for example, the background groundwater methane levels or prevalence of ill-health around development areas.
- 8.29 In the UK, the BGS is undertaking a national survey of methane in groundwater and has long catalogued UK seismicity. Good practice may be for operators to implement or facilitate higher resolution, site-specific surveys as part of their public engagement and social responsibility, a good example of which is the report commissioned by the Polish Ministry of the Environment at 3-Legs Resources’ Lebien LE-2H well (Polish Geological Institute – National Research Institute 2011).
- 8.30 *Open source monitoring data* may help to inspire public confidence in new technologies. The BGS are developing a system called the Energy Test Bed, inspired by the “arms-length” Alberta Environmental Monitoring Agency. Further details can be accessed at <http://esrd.alberta.ca/>
- 8.31 *Citizen science* networks are relatively well established in the US. Three examples are:
- The US National Science Foundation-funded Shale Network (www.shalenet.org), which is mainly focussed on water quality but also collects data on social impacts;
 - The Alliance for Aquatic Resource Monitoring (ALLARM), which provides local communities with scientific tools to assess, protect, and restore waterways;
 - Citizen Shale (citizenshale.org), which is more policy-facing and aims to review and support policies, educate citizens and provide tools for monitoring.
- 8.32 *Community benefit funds* set up to distribute income locally have had success in the wind energy sector (DECC and Renewable UK 2012). Funds can be administered within a community, by a local council or by specialist community fund managers. Supporting investment in community projects may also support local jobs. It has been estimated that hundreds of rural jobs will be supported by community funds in the onshore wind energy sector by 2020.
- 8.33 Respondents to the January 2014 YouGov survey (O’Hara *et al*, 2013) were asked for their opinions on the proposals that operators pay a one-off £100,000 per fracked well, plus 1% of profits to the local community. The majority of people thought that the payments would be to ‘get the community’s support for fracking in their area’ rather than to bring

'benefits to the community'. These results suggest that such payments can be perceived as "buying off" local opposition.

8.34 The UK Onshore Operators Group (UKOOG) has set up a partnership with UK Community Foundations (UKCF) to "ensure community benefit funds are managed and distributed independently of the operators themselves" (UKOOG, 2014).

Examples of good practice by regulators and operators

8.35 The UKOOG launched a Community Engagement Charter for unconventional hydrocarbons in 2013, outlining the provision of "benefits to local communities at the exploration/appraisal stage of £100,000 per well site where hydraulic fracturing takes place", and "a share of proceeds at production stage of 1% of revenues, allocated approximately 2/3rd to the local community and 1/3rd at the county level". Individual operators also have best practice charters –e.g. Statoil's "Operator commitments" (Statoil, 2013).

8.36 In Australia, the states of Queensland and New South Wales have required CBM operators to conduct comprehensive social impact assessments, quarantine certain strategic agricultural land from developments, and use local sources of labour and businesses. The Australian Council of Learned Academies (Cook *et al* 2013) notes that this represents a serious effort to manage the social impacts of CBM developments on local communities, though it is too early to tell if these have had a significant effect.

8.37 The Australian Council of Learned Academies (Cook *et al* 2013) summarise three main routes for maximising benefit to local regions:

- Information sharing, communication and transparency. This may be crucial for public engagement, management of impacts and opportunities, and evaluating the effects of policies;
- Economic diversification leveraged off unconventional gas developments. This is more important in areas with "few comparative advantages";
- A planned and strategic approach to developments to minimise negative impacts and maximise enhancement (c.f. McCluskey and João 2010).

8.38 Much of the public concern has been about the public availability or non-disclosure of data on the composition of fracking fluids. In the US, Frac Focus (<http://fracfocus.org/>) was set up in 2011 by the Ground Water Protection Council and Interstate Oil and Gas Compact Commission as a publically accessible registry for all hydraulic fracturing chemicals. This does not replace any regulatory requirements in any state, but provides a single platform that enables the public to find information on chemical additives being used by operators across the USA.

8.39 However, a recent report by the U.S. Department of Energy Secretary of Energy Advisory Board Task Force Report, detailed on FracFocus (2014), found that "a large fraction of reporting wells claim at least one trade secret exemption".

8.40 According to SEPA’s regulatory guidance on coal bed methane and shale gas (SEPA 2012), “Operators must provide details of all of the chemical additives contained in drilling and fracturing fluids”. SEPA will examine any application for injection and ensure that any substances involved are of a type and at a concentration that will not cause pollution of the water environment.

8.41 Operators have the right to claim that information contained within or attached to an application is commercially confidential. If SEPA agrees for the need for confidentiality, the application will be placed on the register with the confidential information removed. In this case, while the information is not publically available, the regulator will have had clear information about all chemical additives.

Who is defined as the “local” public?

8.42 Opposition to wind farms is partly a function of distance from a development site (Jones & Eiser 2010). UKOOG’s community charter states that “Typically, local communities are defined as those parishes, community councils or properties which are directly located in the vicinity of any producing site or affected by any of the infrastructure required to support a producing site. The exact boundaries of the ‘local community’ will be defined on a site-by-site basis in conjunction with the community.”

8.43 Some of the protesters at UK shale gas and CBM sites are not from local communities. Many of these non-local protestors may be expressing more general concerns about the climate effect of an increased fossil fuel resource, the potential for funding to be diverted from carbon-neutral energy sources and the industrialization of the landscape. Lacey, *et al.* (2012) state that a social license to operate includes the wider public beyond the immediately affected community. While much of the best practice in community engagement focuses on the local communities, the wider community also has a right to make its views heard in any strategic decision-making.

Conclusions

- Public concerns around unconventional gas development include concerns about technical risks such as water contamination, public health and seismicity, but also wider issues such as social impacts on communities, effect on climate targets and trust in operators, regulators and policymakers;
- In addition to the environmental impacts documented in Chapter 6, the process of exploring for shale gas and CBM and, if it happens, eventual scaling up to full production, will have social impacts on a local community;
- Social impacts documented from shale gas and CBM developments in the US and Australia have included job creation, local business investment and investment in infrastructure as well as population growth affecting local housing markets and local demographics; house prices; health effects on animals and people; increased truck traffic; and the impacts of development and protesters on stigmatising local communities;

- Many of these social (and environmental) impacts can be mitigated if they are carefully considered at the planning application stage. Early consultation with communities is vital to identify potential impacts on a community, to scope out potential benefits and to develop plans to mitigate the impacts and enhance the benefits.

Adams, M.B. (2011). Land Application of Hydrofracturing Fluids Damages a Deciduous Forest Stand in West Virginia. *Journal of Environmental Quality*, 40, 1340-1344.

Adgate, J.L., Goldstein, B.D., and McKenzie, L.M. (2014). Potential Public Health Hazards, Exposures and Health Effects from Unconventional Natural Gas Development. *Environmental Science & Technology*. DOI: 10.1021/es404621d

AEA (2012a). Support to the Identification of Potential Risks for the Environment and Human Health arising from Hydrocarbons Operations involving Hydraulic Fracturing in Europe. Report for European Commission DG Environment. AEA/R/ED57281.

AEA (2012b). Climate Impact of Potential Shale Gas Production in the EU. Report for European Commission DG CLIMA. AEA/R/ED57412.

Air Quality Expert Group (2012). Report from the Air Quality Expert Group to the Department for Environment, Food and Rural Affairs; Scottish Government; Welsh Government; and Department of the Environment in Northern Ireland, on Fine Particulate Matter (PM_{2.5}) in the United Kingdom. http://uk-air.defra.gov.uk/reports/cat11/1212141150_AQEG_Fine_Part particulate_Matter_in_the_UK.pdf

Air Quality Consultants (2012). PM_{2.5} in Scotland: A report for SEPA

Allen, D.T., Torres, V.M., Thomas J., *et al* (2013). Measurements of Methane Emissions at Natural Gas Production Sites in the United States, *Proceedings of the National Academy of Sciences of the United States of America* (PNAS). 110 (44), 17768 – 17773.

American Chemistry Council. (2014). U.S. Chemical Investment Linked to Shale Gas Reaches \$100 Billion. Available at: <http://www.americanchemistry.com/Media/PressReleasesTranscripts/ACC-news-releases/US-Chemical-Investment-Linked-to-Shale-Gas-Reaches-100-Billion.html>

Andrews, I J. (2013). The Carboniferous Bowland Shale gas study: geology and resource estimation. British Geological Survey for Department of Energy and Climate Change, London, UK.

Bacon, M J. (1995). Development and Techniques used on the Airth No.1 well in Scotland. Conference Documentation 'Planning for Profit: Coalbed Methane in the UK and Europe' Conference, Selfridge Hotel, London, 30-31 March 1995. IBC Technical Services.

Bailey, N J, Burwood, R and Harriman, G E. (1990). Application of pyrolysate carbon isotope and biomarker technology to organofacies definition and oil correlation problems in the North Sea basins. *Organic Geochemistry*, 16, 1157-1172.

Barker, A and Jones, C (2013) A critique of the performance of EIA within the offshore oil and gas sector. *Environmental Impact Assessment Review* 43, 31-39 DOI: 10.1016/j.eiar.2013.05.001

Barron, H F. (2014). Potential unconventional oil and gas resources in Scotland. British Geological Survey Commissioned Report, CR/14/015.

BGS (2008). Mineral resource map of Glasgow.
<http://www.scotland.gov.uk/Resource/Doc/224888/0060852.pdf>

BGS (2014). Depositing records and digital data.
<http://www.bgs.ac.uk/services/ngdc/records/depositing.html> (checked 27/03/14).

BBC News. (2014). Russia signs 30-year gas deal with China. Available at:
<http://www.bbc.co.uk/news/business-27503017>

Bide, T, Smith, R A, Hyslop, E K, Smith, N J P , Coleman, T and McMillan, A A. (2008). Mineral Resource map for Clackmannanshire, Fife and Falkirk. OR/08/12.
<http://www.scotland.gov.uk/Resource/Doc/224888/0060849.pdf>

Bloomberg New Energy Finance. (2013). The Economic Impact on UK Energy Policy of Shale Gas and Oil. Available at: <http://about.bnef.com/white-papers/the-economic-impact-on-uk-energy-policy-of-shale-gas/>

Britain Thinks (2012). Public attitudes to Natural Gas from Shale in Blackpool, Fylde and West Lancashire. [http://britainthinks.com/sites/default/files/Public Attitudes%20to%20Natural%20Gas%20from%20Shale%20in%20Blackpool,%20Fylde%20and%20West%20Lancashire.pdf](http://britainthinks.com/sites/default/files/Public%20Attitudes%20to%20Natural%20Gas%20from%20Shale%20in%20Blackpool,%20Fylde%20and%20West%20Lancashire.pdf)

Browne, M. A. E., Dean, M. T., HALL, I H S, McADAM, A D, MONRO, S K and CHISHOLM, J I. 1999. A lithostratigraphical framework for the Carboniferous rocks of the Midland Valley of Scotland. British Geological Survey Research Report. RR/99/07.

Bunch, A.G., Perry, C.S., Abraham, L. , Wilkoff D.S., Tachovsky J.A., Hixon J.G., Urban J.D., Harris MA., and Haws L.C. (2014) Evaluation of Impact of Shale Gas Operations in the Barnett Shale Region on Volatile Organic Compounds in Air and Potential Human Health Risks. Science of the Total Environment 468–469, 832–842.

Cameron, I B and McAdam, A D. (1978). Oil-shales of the Lothians, Scotland:present resources and former workings. Report of the Institute of Geological Sciences, No. 78.

Carruthers, E.G. Caldwell, W. Bailey, E.M. and Conacher. H.R.J., 1927, The Oil-Shales Of The Lothians. Third edition. Memoirs of the Geological Survey of Great Britain (Scotland). Geological Survey, Edinburgh. 274pp.

Cathles III LM., Brown L., Taam M. and Hunter A. (2012). A commentary on “The greenhouse-gas footprint of natural gas in shale formations” by R.W. Howarth, R. Santoro and Anthony Ingraffea Climatic Change. 113, 525-535.

Caulton, DR., Shepsona, PB , Santoroc, RL., Sparks, JP., Howarth, RW., Ingraffea, AR., Cambaliza, MOL. , Sweeney, C., Karion, A., Davis, KJ., Stirm, BH., Montzka, SA. and Miller, BR. (2014). Toward a better understanding and quantification of methane emissions from shale gas development PNAS doi: 10.1073/pnas.1316546111

Charpentier, R R and Cook, T A. (2011). USGS Methodology for Assessing Continuous Petroleum Resources. U.S. Geological Survey Open-File Report 2011–1167

Cobbing, J., Ó Dochartaigh, B.É. (2007). Hydrofracturing water boreholes in hard rock aquifers in Scotland. *Quarterly Journal of Engineering Geology and Hydrogeology*, 40, 181–186.

Colborn, T., Kwiatkowski, C. Shultz, K. and Bachran, M. (2011). Natural Gas Operations from a Public Health Perspective. *Human and Ecological Risk Assessment*. 17:5, 1039 – 1056. DOI: 10.1080/10807039.2011.605662

Cook, P, Beck, V, Brereton, D, Clark, R, Fisher, B, Kentish, S, Toomey, J and Williams, J. (2013). Engineering energy: unconventional gas production. Report for the Australian Council of Learned Academies. Available at: www.acola.org.au

Creedy, D P. (1991). An introduction to geological aspects of methane occurrence and control in British deep coal mines. *Quarterly Journal of Engineering Geology*, 24, 209-220. doi: 10.1144/GSL.QJEG.1991.024.02.04

Cuadrilla Resources. (2014) What we do. [online] <http://www.cuadrillaresources.com/what-we-do/> (checked 31/03/14)

Cuadrilla Ltd. What We Do: Hydraulic Fracturing – Fracturing Fluid. (2014). [online] <http://www.cuadrillaresources.com/what-we-do/hydraulic-fracturing/fracturing-fluid/> (checked 15/04/14)

Davies R. and Foulger G. (2012). Response To DECC Consultation On Preese Hall Shale Gas Fracturing: Review & Recommendations For Induced Seismic Mitigation https://www.dur.ac.uk/resources/dei/DECCconsultation_DurhamUniversity.pdf

Davies R.J., Foulger,G, Bindley,A, and Styles, P. (2013). Induced Seismicity and Hydraulic Fracturing for the Recovery of Hydrocarbons, Review article, *Marine and Petroleum Geology*, v. 45, Pages 171-185.

Davies, R.J., Almon, S., Ward, R.S., Jackson, R.B., Adams, C., Worrall, Herringsha, Gluyas, J.G. and Whitehead, M.A. (2014). Oil and gas wells and their integrity: Implications for shale and unconventional resource exploitation, *Marine and Petroleum Geology*.

DECC. (2010). The Unconventional Hydrocarbon Resources of Britain's Onshore Basins - Coalbed Methane (CBM). HM Government, Department of Energy and Climate Change (DECC), London. 40pp.

DECC. (2010a). The unconventional hydrocarbon resources of Britain's onshore basins - shale gas. https://www.og.decc.gov.uk/UKpromote/onshore_paper/UK_onshore_shalegas.pdf

DECC. (2010b). The hydrocarbon prospectivity of Britain's onshore basins. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/66170/uk-onshore-prospectivity.pdf

DECC. (2013). Regulatory Roadmap: Onshore oil and gas exploration in the UK regulation and best practice.

DECC. (2014). Consultation on the Environmental Report for further onshore oil and gas licensing. [online] <https://econsultation.decc.gov.uk/decc-policy/consultation-env-report-further-oil-gas-licensing/> (checked 27/03/14)

DECC and Renewable UK. (2012). Onshore wind direct wider economic impacts. 100 pp. <http://www.renewableuk.com/en/publications/reports.cfm/BiGGAR>

DECC. (2012). DECC Public Attitudes Tracker survey – Wave 9. 10 pp. <https://www.gov.uk/government/publications/public-attitudes-tracking-survey-wave-9>

DECC. (2013). Strategic Environmental Assessment for Further Onshore Oil and Gas Licensing – Environmental Report by AMEC. Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/273997/DEC_C_SEA_Environmental_Report.pdf

DECC. (2014). Underground Drilling Access - Consultation on Proposal for Underground Access for the Extraction of Gas, Oil or Geothermal Energy. Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/313576/Consultation_on_Underground_Drilling_Access_final_web_version.pdf

DEFRA. (2011). Guidelines for Environmental Risk Assessment and Management, Green Leaves III. 81pp. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/69450/pb13670-green-leaves-iii-1111071.pdf

DEFRA. (2007). The Air Quality Strategy for England, Scotland, Wales and Northern Ireland. [online] <http://archive.defra.gov.uk/environment/quality/air/airquality/strategy/documents/air-qualitystrategy-vol1.pdf>. (checked 27/03/14).

Dominiczak, P. (2014). David Cameron: Britain has a 'duty' to frack. The Telegraph, 26 March 2014. Available at: <http://www.telegraph.co.uk/earth/energy/fracking/10723294/David-Cameron-Britain-has-a-duty-to-frack.html>

Dreyer, I. and Stang, G. (2013). The shale gas 'revolution': Challenges and implications for the EU. European Union Institute for Security Studies. Available at: http://www.iss.europa.eu/uploads/media/Brief_11.pdf

DTI. (2001). UK Capability: Coalbed Methane Extraction and Utilisation. HM Government, Department of Trade and Industry, London. 20pp.

Economic and Social Research Council (2013) <http://www.esrc.ac.uk/news-and-events/features-casestudies/features/20493/carousel-fracking-and-public-dialogue.aspx>

Emeleus, H, and Bell, B R. (2005). British Regional Geology: the Palaeogene volcanic districts of Scotland (Fourth edition). (Keyworth, Nottingham: British Geological Survey.)

Environment Agency. (2011). Shale Gas, North West - Monitoring of Flowback Water. [online] [http://www.environment-agency.gov.uk/static/documents/Business/6th Dec - Shale gas - North West - Monitoring of flowback water - update \(3\).pdf](http://www.environment-agency.gov.uk/static/documents/Business/6th Dec - Shale gas - North West - Monitoring of flowback water - update (3).pdf). (checked 31/03/14).

Ernst & Young. (2014). Getting Ready for UK Shale Gas. Available at: http://www.ukoog.org.uk/images/ukoog/pdfs/Getting_ready_for_UK_shale2_gas_FINAL2022.04.14.pdf

Esteves, A.M., Franks, D. and Vanclay, F. (2012). The state of the art in social impact assessment, *Impact Assessment and Project Appraisal*, 30(1), 35-44.

European Commission. (2013). Review of the Environmental Impact Assessment (EIA) Directive <http://ec.europa.eu/environment/eia/review.htm>

European Commission. (2014). Commission Staff Working Document. Impact Assessment Accompanying the Document Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Exploration and Production of Hydrocarbons (such as Shale Gas) using High Volume Hydraulic Fracturing in the EU.

European Commission. (2014). Commission Recommendation of 22 January 2014 on Minimum Principles for the Exploration and Production of Hydrocarbons (such as Shale Gas) using High Volume Hydraulic Fracturing.

European Commission. (2012). Joint Research Centre, Institute for Energy and Transport. Unconventional Gas: Potential Energy Market Impacts in the European Union.

European Commission. (2013). DG Environment. Analysis and presentation of the results of the public consultation "Unconventional fossil fuels (e.g. shale gas) in Europe.

Faith, J. (2013). Could fracking change the face of buy-to-let? Mortgage Solutions online blog: <http://www.mortgagesolutions.co.uk/mortgage-solutions/blog-post/2276519/could-fracking-change-the-face-of-buytolet>

Forster, D., Jonathan, P. (2012). Climate impact of potential shale gas production in the EU - Final Report (Final Report - Review No. Issue 2). AEA TEchnology Inc. for the European Commission

Friends of the Earth Scotland (2004) Love Thy Neighbour? The Potential for Good Neighbour Agreements in Scotland. 60pp.

Golding, S.D., Uysal, I.T., Boreham, C.J., Kirste, D., Baublys, K.A., and Esterle, J.S. (2011). Adsorption and mineral trapping dominate CO₂ storage in coal systems. *Energy Procedia*, 4: 3131-3138.

Gray, I M., and Edwards-Jones, G. (1999). A Review of the Quality of Environmental Impact Assessments in the Scottish Forestry Sector. *Forestry*, 72, 1 : 1 - 10

- Green, C.A., Styles, P. and Baptie, B.J. (2012), Preese Hall shale gas fracturing for induced seismic mitigation, DECC Report pp. 26
(<http://www2.epa.gov/sites/production/files/documents/comparisonofhffluidscompositionwithproducedformationwater.pdf>)
- Hallet, D, Durant, G P. and Farrow, G E. (1985). Oil exploration and production in Scotland. *Scottish Journal of Geology*, 21, 4, 547-570. doi: 10.1144/sjg21040547
- Halliburton. (2009). Coalbed Methane Development – a Vital Part of the Total Energy Mix. Halliburton, Houston. 23pp.
- Happer C., Philo G. and Froggatt A. (2012). Climate change and energy security: Assessing the impact of information and its delivery on attitudes and behaviour. UKERC/RR/HQ/2012/002
- Harris and van Batenburg (1999), A comparison of freshwater- and seawater-based borate-crosslinked fracturing fluids, Society of Petroleum Engineers International Symposium on Oilfield Chemistry: Houston, Texas. Available at: <http://www.onepetro.org/mslib/servlet/onepetropreview?id=00050777>
- Health Protection Agency. (2009). An Introduction to Land Contamination for Public Health Professionals. Chemical Hazards and Poisons Division Health Protection Agency, Cardiff. 52pp. (Available on-line: http://www.hpa.org.uk/webc/hpawebfile/hpaweb_c/1242198452810; last accessed 12-4-2014).
- Health Protection Network. (2008). Communicating with the Public About Health Risks. Health Protection Network Guidance 1. Health Protection Scotland, Glasgow. Available at: <http://www.documents.hps.scot.nhs.uk/about-hps/hpn/risk-communication.pdf>
- Hesselbo, S P, Oates, M J and Jenkyns, H C. (1998). The lower Lias Group of the Hebrides Basin. *Scottish Journal of Geology*, 34, 23–60. doi: 10.1144/sjg34010023
- Highwood EJ, Shine KP, Hurley MD and Wallington TJ. (1999) Estimation of direct radiative forcing due to non-methane hydrocarbons *Atmospheric Environment* 33, 759-767
- House of Commons. (2011). Energy and Climate Change - Written Evidence. Supplementary memorandum submitted by the Department of Energy and Climate Change (SG 01b). [online] <http://www.publications.parliament.uk/pa/cm201012/cmselect/cmenergy/795/795we04.htm> (checked 27/03/14)
- Howarth R.W, Santoro, R., Ingraffea, A. (2011). Methane and the Greenhouse-Gas Footprint of Natural Gas from Shale Formations. *Climatic Change*. 106, 679-690.
- Howarth R.W, Santoro, R., Ingraffea, A. (2012). Venting and Leaking of Methane from Shale Gas Development: Response to Cathles *et al.* *Climatic Change*. 113, 537-549.
- Hudson, J D and Trewin, N H. (2002). Jurassic. 323–350 in *The Geology of Scotland*. Trewin, N H (editor). (London: The Geological Society.) ISBN 1-86239-105-X.

Husain, T. M., Yeong, L. C., Saxena, A., Cengiz, U., Ketineni, S., Khanzode, A. and Muhamad, H. (2011). Economic Comparison of Multi-Lateral Drilling over Horizontal Drilling for Marcellus Shale Field Development. Available at: http://www.ems.psu.edu/~elsworth/courses/egee580/2011/Final%20Reports/fishbone_report.pdf

ICM. (2013) Opinion Poll: Britain Split on Fracking. Available at <http://www.icmresearch.com/britain-split-on-fracking>

Illsley, B. M. (2002). Good Neighbour Agreements: the first step to environmental justice? *Local Environment*, 7(1): 69-79.

Insley, J. (2012). Worry for homeowners who face the threat of fracking. *The Guardian*, 23 June 2012. Available at: <http://www.theguardian.com/money/2012/jun/23/fracking-undermine-value-home>

International Energy Agency. (2012). World Energy Outlook 2012. Available at: www.iea.org

International Gas Union. (2013). Wholesale Gas Price Survey - 2013 Edition - A global review of price formation mechanisms 2005-2012. Available at: http://www.igu.org/sites/default/files/node-page-field_file/IGU%20-%20Wholesale%20Gas%20Price%20Survey%20-%202013%20Edition.pdf

Jackson R.B. *et al.* (2013). Increased stray gas abundance in a subset of drinking water wells near Marcellus shale gas extraction. *Proc. Nat. Acad. Sci.* 110, 11250-11255

Jackson, RB, Vengosh, A, Darrah, TH, Warner, NR, Down, A, Poreda, RJ, Osborn, SG, Zha, K, Karr, JD. (2013). Increased stray gas abundance in a subset of drinking water wells Marcellus shale gas extraction. *Proc. Nat. Acad. Sci.* 110, 11250-11255.

João, E, F Vanclay and L den Broeder (2011), Emphasising enhancement in all forms of impact assessment: introduction to a special issue. *Impact Assessment & Project Appraisal*, September, 29(3): 170–180.

Jardine, C.N., Boardman, B., Osman, A., Vowles, J., and Palmer, J. (2009). Chapter 8: Coal Mine Methane. In: Jardine, C.N., Boardman, B., Osman, A., Vowles, J., and Palmer, J. (editors) *Methane UK*. (2013). Environmental Change Institute, University of Oxford. pp. 64-71. (available on-line at: <http://tinyurl.com/lcryduw>; last accessed 19-8-2013).

Jarvis, A.P., and Younger, P.L. (2000). Broadening the scope of mine water environmental impact assessment - a UK perspective. *Environmental Impact Assessment Review*, 20, pp 85 – 96.

Jaspal, R., Turner, A. and Nerlich, B. (in press). Fracking on YouTube: Exploring Risks, Benefits and Human Values. *Environmental Values*. (Available at <https://www.dora.dmu.ac.uk/xmlui/handle/2086/8823>)

Jaspal, R. and Nerlich, B. (2014). Fracking in the UK press: Threat dynamics in an unfolding debate. *Public Understanding of Science*. vol. 23 no. 3 348-363_DOI: 10.1177/0963662513498835

Jones, C. & Eiser, J.R. (2010), Understanding 'local' opposition to wind development in the UK: How big is a backyard? *Energy Policy*, 38, 3106-17, DOI: 10.1016/j.enpol.2010.01.051

Jones, N S, Holloway, S, Creedy, D P, Garner, K, Smith, N J P, Browne, M A E and Durucan, S. (2004). UK Coal Resource for New Exploitation Technologies. Final Report. British Geological Survey Commissioned Report CR/04/015N. Cleaner Coal Technology Programme, COAL R271, November 2004.

Kovats S., Depledge M, Haines A, Fleming L.E., Wilkinson P., Shonkoff S.B., Scovronick N. (2014). The health implications of fracking, *The Lancet*, Volume 383, 757 - 758, doi:10.1016/S0140-6736(13)62700-2

Kuma, J.S., Younger, P.L., and Bowell, R.J. (2002). Expanding the hydrogeological base in mining EIA studies: A focus on Ghana. *Environmental Impact Assessment Review*, 22, pp 273 - 286.

Lacey, J., Parsons, R., & Moffat, K. (2012). Exploring the concept of a Social License to Operate in the Australian minerals industry: Results from interviews with industry representatives EP125553. Brisbane: CSIRO.

Law A., Hays J. Shonkoff S.B., Finkel M.L. (2014). Public Health England's draft report on shale gas extraction *British Medical Journal* 348 doi: 10.1136/bmj.g2728

Lewis, D. and Taylor, C. (2013). Getting Shale Gas Working. Institute of Directors Report. Available at: <http://www.iod.com/influencing/policy-papers/infrastructure/infrastructure-for-business-getting-shale-gas-working>

Mackay, D. and Stone, T. (2013). Potential greenhouse gas emissions associated with shale gas production and use. Department of Energy & Climate Change (DECC).

Mair, R., Bickle, M., Goodman, D., Koppelman, B., Roberts, J., Selley, R., Shipton, Z., Thomas, H., Walker, A., Woods, E., & Younger, P.L. (2012). Shale gas extraction in the UK: a review of hydraulic fracturing. Royal Society and Royal Academy of Engineering, London. 76pp. (Available on-line: http://royalsociety.org/uploadedFiles/Royal_Society_Content/policy/projects/shale-gas/2012-06-28-Shale-gas.pdf).

Marshall, J E A, Brown, J F, and Hindmarsh, S. (1985). Hydrocarbon source rock potential of the Devonian rocks of the Orcadian Basin. *Scottish Journal of Geology*, 21, 301-320.

Martin, R. (2013). Shale Gas Export Boom: Don't Celebrate Yet. *Forbes*. 18th October 2013. <http://www.forbes.com/sites/pikeresearch/2013/10/18/shale-gas-export-boom-dont-celebrate-yet/>

McCluskey, D. and João, E. (2010). The promotion of environmental enhancement in Strategic Environmental Assessment. *Environmental Impact Assessment Review*, 31: 344-351.

McElreath, D. (2011). Comparison of Hydraulic Fracturing Fluids Composition with Produced Formation Water following Fracturing - Implications for Fate and Transport. Hydraulic Fracturing Technical Workshop 3 - Contaminant Identification, Transformation & Transport Theme-Technical Presentation Session 2: Chemical Mobility and Potential Pathways. Available at:

<http://www2.epa.gov/sites/production/files/documents/comparisonofhffluidscompositionwithproducedformationwater.pdf>

McKay, J. (2012). Scotland's First Oil Boom: The Scottish Shale Oil Industry, 1851-1914. John Donald Short Run Press, Edinburgh. 320pp.

Miyazaki, B. (2009). Well integrity: an Overlooked Source of Risk and Liability for Underground Natural Gas Storage. Lessons Learnt from Incidents in the USA. Geological Society, London, Special Publications, 313, 163-172.

Molofsky, LJ, Connor, JA, Farhat, SK, Wyllie, AS, and Wagner, T. (2011). Methane in Pennsylvania water wells unrelated to Marcellus Shale fracturing. Oil and Gas Journal, 109, 49, 1-13

Monaghan, A A. (2013). Model metadata report for the Midland Valley of Scotland Regional Model 2012/13. British Geological Survey Internal Report, IR/13/013. 34pp.

Monaghan, A.A. 2014. The Carboniferous shales of the Midland Valley of Scotland: geology and resource estimation. British Geological Survey for Department of Energy and Climate Change, London, UK.

Moore, T. (2012). Coal bed methane: A review International Journal of Coal Geology 101. 36–81.

Muehlenbachs L., Spiller E. and Timmins C. (2014). The housing market impacts of shale gas development", NBER Working Paper 19796.

Murchison, R. I. (1859). On the succession of the older rocks in the northernmost counties of Scotland; with some observations on the Orkney and Shetland Islands. Q.J.Geol. Soc. Lond. 15,

Myhre, G., D. Shindell, F.-M. Bréon, W. Collins, J. Fuglestedt, J. Huang, D. Koch, J.-F. Lamarque, D. Lee, B. Mendoza, T. Nakajima, A. Robock, G. Stephens, T. Takemura and H. Zhang. (2013): Anthropogenic and Natural Radiative Forcing. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

National Petroleum Council. (2011). Sustainable Drilling of Onshore Oil and Gas Wells. Working Document of the NPC North American Resource Development Study. Available at:

http://www.npc.org/prudent_development-topic_papers/2-23_sustainable_drilling_of_onshore_oil_and_gas_wells_paper.pdf

National Physical Laboratories (NPL). (2013). Fugitive Methane Emissions project. [online] <http://www.npl.co.uk/carbon-measurement/european-consortium-to-combat-methane-emissions> (checked 15/04/14)

NCB. (1958). A short history of the Scottish coal-mining industry. National Coal Board, Scottish Division, Edinburgh. 116pp.

NRC. (2012). Induced seismicity potential in energy technologies, National Research Council of the National Academies: Washington DC.
<http://i2.cdn.turner.com/cnn/2012/images/06/15/induced.seismicity.prepublication.pdf>

O'Faircheallaigh, C. (1999). Making Social Impact Assessment Count: A Negotiation-Based Approach for Indigenous Peoples. *Society and Natural Resources*, 12(1), 63-80.

OGUK. (2012). Guidelines for the suspension and abandonment of wells, The United Kingdom Offshore Oil and Gas Industry Association Limited (trading as Oil & Gas UK)

O'Hara S., Humphrey M., Jaspal R., Nerlich B. and Knight W. (2013). Public Perception of Shale Gas extraction in the UK: Is the Balcombe effect taking hold? Available at <http://nottspolitics.org/wp-content/uploads/2013/10/public-perceptions-of-shale-gas-in-the-UK-september-2013-1-2.pdf>

O'Hara, S., Humphrey, M., Jaspal, R., Nerlich, B. and Knight, W. (2014). Public Perception of Shale gas extraction in the UK: Is the Balcombe effect taking hold protests in July-August 2013. 10 pp. Available at <http://www.scribd.com/doc/131787519/public-perceptions-of-shale-gas-in-the-UK-January-2014-pdf>

Parnell, J. (1988). Lacustrine petroleum source rocks in the Dinantian Oil Shale Group, Scotland: a review. In Fleet, A. J., Kelts, K. & Talbot, M. R. (eds), *Lacustrine Petroleum Source Rocks*, Geological Society Special Publication No. 40, pp. 235-246.

Pearson I., Zeniewski P, Gracceva F, Zastera P, McGlade C, Sorrell S, Speirs J, Thonhauser G. (2012). Unconventional Gas: Potential Energy Market Impacts in the European Union. EU JRC Scientific and Policy Reports
http://ec.europa.eu/dgs/jrc/downloads/jrc_report_2012_09_unconventional_gas.pdf

Philippe and Partners. (2011). Final Report on Unconventional Gas in Europe.

Polish Geological Institute – National Research Institute. (2011). Environmental Aspects of Hydraulic Fracturing Treatment Performed on the łebień LE-2H Well: Final Report. Available at: <http://www.pgi.gov.pl/en/mineral-resources-en/shale-gas/4749-report-lebien.html>

Property and Land Information website: <http://www.palilt.com/blog/fracking-effects-house-prices>

Public Health England. (2013). Review of the Potential Public Health Impacts of Exposure to Chemical and Radioactive Pollutants as a Result of Shale Gas Extraction. Draft for Comment. 2013, final version to be published shortly.

Read, W A, Browne, M A E, Stephenson, D and Upton, B J G. (2002). Carboniferous. In: Trewin N H (ed) The Geology of Scotland. Fourth Edition. The Geological Society, London, 251-300.

Rogers, H. (2011). Shale gas--the unfolding story. Oxford Review of Economic Policy, 27(1), 117-143.

Scott EM, Bryant C, Carmi I, Cook G, Gulliksen S , Harkness D, Heinemeier J , McGee E, Naysmith P , Possnert G , van der Plicht H, van Strydonck M. (2004). Precision and accuracy in applied C-14 dating: some findings from the Fourth International Radiocarbon Inter-comparison. Journal Of Archaeological Science. 31; 9; 1209-1213 DOI: 10.1016/j.jas.2002.06.001

Scottish Government. (2010). Scottish Planning Policy. [online]
<http://www.scotland.gov.uk/Publications/2010/02/03132605/8> (checked 27/03/14).

Scottish Government. (2011). Circular 3/2011. The Town And Country Planning (Environmental Impact Assessment) (Scotland) Regulations 2011. [online]
<http://www.scotland.gov.uk/Publications/2011/06/01084419/0> (checked 27/03/14).

Scottish Government. (2012). Electricity Generation Policy Statement. [online]
<http://scotland.gov.uk/Topics/Business-Industry/Energy/EGPS2012/DraftEPGS2012> (checked 27/03/14).

Scottish Government. (2013). Communication: Policy on Unconventional Gas. [online]
<http://news.scotland.gov.uk/News/Policy-on-unconventional-gas-547.aspx> (checked 27/03/14).

Scottish Parliament Information Centre (SPICe). (2012). SPICe briefing: Peatlands and Climate Change http://www.scottish.parliament.uk/ResearchBriefingsAndFactsheets/S4/SB_12-28.pdf

SEAI (2011). Good Practice Wind, TCS 6 Carbon Accounting. Sustainable Energy Authority Ireland.
http://www.seai.ie/Renewables/Wind_Energy/Good_Practice_Wind/TCS_6_Carbon_Accounting.pdf

SEPA. (2012). Regulatory Guidance: Coal Bed Methane and Shale Gas. Version 121119. [online]
http://www.sepa.org.uk/customer_information/energy_industry/unconventional_gas/idoc.aspx?docid=c684b401-ad28-4d30-a4cb-1467f395c100&version=-1 (checked 27/03/14)

SEPA. (2013). Unconventional Gas Current Activities 2013
http://www.sepa.org.uk/customer_information/energy_industry/unconventional_gas/current_activities.aspx

Skone, T.J., Littlefield J. and Marriott J. (2011). Life Cycle Greenhouse Gas Inventory of Natural Gas Extraction, Delivery and Electricity Production DOE/NETL-2011/1522.

Sloss, L.L. (2005). Coalbed methane emissions - capture and utilisation. International Energy Agency, Clean Coal Centre, report no. CCC/104. International Energy Agency, London. 56pp.

Smith, J.U., Graves, P., Nayak D,R., Smith, P., Perks, M., Gardiner, B., Miller., D. Nolan, A., Morrice, J., Xanakis, G., Waldron, S., Drew, S. (2011). Carbon implications of windfarms located on peatlands – update of the Scottish Government carbon calculator tool 2CR/2010.05 <http://www.scotland.gov.uk/Resource/Doc/917/0121468.pdf>

Smith, R. A., Bide, T., Hyslop, E. K. , Smith, N. J. P. , Coleman, T., and McMillan, A. A. (2008a). Mineral Resource map for East Lothian, Midlothian, West Lothian and City of Edinburgh. OR/08/13. <http://www.scotland.gov.uk/Resource/Doc/224888/0060850.pdf>

Smith, R. A., Bide, T., Hyslop, E. K. , Smith, N. J. P. , Coleman, T., and McMillan, A. A. (2008b). Mineral Resource map for North Ayrshire, East Ayrshire and South Ayrshire. OR/08/014. <http://www.scotland.gov.uk/Resource/Doc/224888/0060851.pdf>

Smith, R. A., Bide, T., Hyslop, E. K., Smith, N. J. P., Coleman, T., and McMillan, A. A. (2008c). Mineral Resource map for Inverclyde, West Dunbartonshire, East Dunbartonshire, Renfrewshire, East Renfrewshire, North Lanarkshire, South Lanarkshire and City of Glasgow. OR/08/15. <http://www.scotland.gov.uk/Resource/Doc/224888/0060852.pdf>

Statoil. (2013). Shale/Operator Commitments. Available at: <http://www.statoil.com/en/OurOperations/ExplorationProd/ShaleGas/Downloads/Statoil%20Shale%20Operator%20Commitments-2013.pdf>

Stevens, P. (2012). The ‘Shale Gas Revolution’: Developments and Changes. Chatham House Briefing Paper. Available at: http://www.chathamhouse.org/sites/default/files/public/Research/Energy,%20Environment%20and%20Development/bp0812_stevens.pdf

Tewksbury, J. J., Levey, D. J., Haddad, N. M., Sargent, S., Orrock, J. L., Weldon, A., Danielson, B.J., Brinkerhoff, J., Damschen E. I. and Townsend, P. (2002). Corridors affect plants, animals, and their interactions in fragmented landscapes. *Proceedings Of The National Academy Of Sciences Of The United States Of America*. 99,20,12923-12926 DOI: 10.1073/pnas.202242699

Thorogood J.L. and Younger. P. (2014). Discussion of Oil and gas wells and their integrity: Implications for shale and unconventional resource exploitation² by R. J. Davies, S. Almond, R.S., Ward, R.B. Jackson, C. Adams, F. Worrall, L.G. Herringshaw, J.G. Gluyas and M.A. Whitehead. *Marine and Petroleum Geology* 2014 (doi: <http://dx.doi.org/10.1016/j.marpetgeo.2014.03.001>)).

TNO. (2009). Inventory non-conventional gas. TNO-034-UT-2009-00774/B.

Tollefson, J. (2012). Air sampling reveals high emissions from gas fields. *Nature* 482, 139-140.

UKOOG (2014) <http://www.ukoog.org.uk/about-ukoog/press-releases/66-how-to-engage-with-shale-gas-hydraulic-fracturing-planning-and-permitting>

UKOOG (2014) <http://www.ukoog.org.uk/about-ukoog/press-releases/68-united-kingdom-onshore-operators-group-announces-next-steps-in-the-formation-of-its-community-benefits-scheme>

Underhill, J. R., Monaghan, A. A. and Browne, M. A. E. (2008). Controls on structural styles, basin development and petroleum prospectivity in the Midland Valley of Scotland. *Journal of Marine and Petroleum Geology*, 25, 1000-1022. doi.org/10.1016/j.marpetgeo.2007.12.002.

US Department of Commerce Bureau of Economic Analysis. (2014). National Income and Product Accounts. Available at:
<http://bea.gov/newsreleases/national/GDP/GDPnewsrelease.htm>

U.S. Department of Energy. (2014). Secretary of Energy Advisory Board Task Force Report on FracFocus. Available at:
<http://energy.gov/sites/prod/files/2014/03/f8/FracFocus%20TF%20Report%20Final%20Draft.pdf>

US Department of Energy. (2009). US Modern Shale Gas Development in the United States: A Primer. Tulsa, Oklahoma, USA: U.S. Department of Energy, Office of Fossil Energy and National Energy Technology Laboratory prepared by Ground Water Protection Council, Oklahoma City and ALL Consulting.

U.S. Department of Energy. (2013). How is Shale Gas Produced?: Available at:
http://energy.gov/sites/prod/files/2013/04/f0/how_is_shale_gas_produced.pdf

U.S. Energy Information Administration (USEIA). (2011a). World Shale Gas Resources: an initial assessment of 14 regions outside the United States. Report prepared by Advanced Resources International Inc. www.eia.gov/analysis/studies/worldshalegas/.

US Energy Information Administration. (2013). Energy-related carbon dioxide emissions declined in 2012. Available at: <http://www.eia.gov/todayinenergy/detail.cfm?id=10691>

US Energy Information Administration. (2013). Analysis and Projections: Technically Recoverable Shale Oil and Shale Gas Resources: An Assessment of 137 Shale Formations in 41 Countries Outside the United States. Available at:
<http://www.eia.gov/analysis/studies/worldshalegas/>

US Energy Information Administration. (2014). US Crude Oil and Natural Gas Proved Reserves. Available at: <http://www.eia.gov/naturalgas/crudeoilreserves/>

US Environmental Protection Agency (US EPA). (2012). EPA's Air Rules for the Oil & Natural Gas Industry - Summary Of Key Changes To The New Source Performance Standards. Available at:
<http://www.epa.gov/airquality/oilandgas/pdfs/20120417changes.pdf>

US Environmental Protection Agency. (2013). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2011. [online] <http://www.epa.gov/climatechange/Downloads/ghgemissions/US-GHG-Inventory-2013-Main-Text.pdf> (checked 31/03/14).

USGS (2000). Water Produced with Coal-Bed Methane. Factsheet FS 156-00

Walker and Devine-Wright. (2008). Community renewable energy: What should it mean? *Energy Policy* Volume 36, Pages 497–500

Warner NR, *et al.* (2012). Geochemical evidence for possible natural migration of Marcellus Formation brine to shallow aquifers in Pennsylvania. *Proc. Natl. Acad. Sci.* 109(30):11961–11966.

World Energy Council. (2010). 2010 Survey of Energy Resources. World Energy Council (WEC), London. 618pp.

Westaway and Younger, P. L. (2014). Quantification of macroseismic effects of induced seismicity caused by hydraulic fracturing for shale gas exploitation in the UK. *Quarterly Journal of Engineering Geology and Hydrogeology*. In review

Williams, L. (2013). Framing Fracking: Public responses to potential unconventional fossil fuel exploitation in the North of England. Unpublished Masters thesis, Durham University. Available at: <http://etheses.dur.ac.uk/9444/>

Witter, R., Stinson, K., Sackett, H., Putter, S., Kinney, G., Teitelbaum, D., & Newman, L. (2008). Potential exposure-related human health effects of oil and gas development: A white paper. Colorado School of Public Health.

Yost (2011), Water management during shale gas development: current R&D efforts, conference presentation, US Department of Energy National Energy Technology Laboratory. Available at: http://www.hartenergyconferences.com/UserFiles/File/DUG_2011/Workshop_Presentations/Albert_Yost.pdf

Younger, P.L. (2007). *Groundwater in the environment: an introduction*. Blackwell Publishing, Oxford. 318pp.

Younger, P.L. (2013). Deep geothermal: the Newcastle Science Central Borehole. *Geothermal Association of Ireland Newsletter*, 21: 9 – 13.

Younger P.L. and Sapsford D.J. (2004). Evaluating the potential impact of opencast coal mining on water quality (Groundwater Regulations 1998): An Assessment Framework for Scotland. [online]
http://www.sepa.org.uk/water/water_regulation/regimes/groundwater/idoc.ashx?docid=493183e8-f379-44bf-9942-9871174ead06&version=-1 (checked 31/03/14)

Zielinska, B., Fujita, E., Campbell, D. (2010). Monitoring of Emissions from Barnett Shale Natural Gas Production Facilities for Population Exposure Assessment, Mickey Leland National Urban Air Toxics Research Center.

Zoback, M.D. (2012). Managing the seismic risk posed by wastewater disposal. *Earth* 57(4):38–43.

Members of the Independent Expert Scientific Panel on Unconventional Oil & Gas

Dr Chris Masters CBE

Dr Chris Masters CBE, FRSE is currently the Chairman of Energy Assets Plc. He also holds a number of other non-executive directorships, including Speedy Hire Plc and The Crown Agents. He is a member of the Court of Edinburgh University and Independent Co-Chair of the Scottish Science Advisory Council. Full time executive positions have included Chief Executive of Christian Salvesen PLC and Executive Chairman of Aggreko plc. In a non-executive capacity he has chaired the Scottish Higher Education Funding Council, Babbie Group Ltd., the Scottish Media group PLC, Sagentia Group PLC, Voxar Ltd and the Festival City Theatres Trust in Edinburgh. He has also served on the boards of the John Wood Group, Alliance Trust, British Assets, Scottish Widows, Scottish Opera and the Scottish Chamber Orchestra.

A research chemist by training, he has extensive experience of international business, is a fellow of the Royal Society of Edinburgh and has received honorary degrees from the Universities of Strathclyde, St Andrews, Edinburgh and Dundee Abertay.

Professor Zoe Shipton, Professor of Geological Engineering, Department of Civil Engineering, Strathclyde University

Professor Shipton is a structural geologist working on fault growth processes, the link between faulting and fluid flow, and the structure of earthquake faults. She also conducts research into quantifying geological uncertainties and the perception and communication of risk and uncertainty. Previously, Zoe was a senior lecturer at the University of Glasgow, Department of Geographical and Earth Sciences (2004-2010), a lecturer at the Department of Geology at Trinity College Dublin (2001-2004), and a post-doctoral research fellow at Utah State University (1999-2001). She is Chair of the Tectonic Studies Group, and is a member of the Royal Society and Royal Academy of Engineering working group on "Shale gas extraction in the UK: a review of the scientific and engineering evidence". In 2010 she was awarded the Geological Society of London William Smith Fund for excellence in contributions to applied and economic aspects of geoscience.

Professor Shipton has carried out consultancy work for Cluff Geothermal Limited, BHP Billiton, StatoilHydro and Todd Energy, and has held research grants from UK and Irish research councils, Total Oil, Geochemica, Carnegie Trust for the Universities of Scotland, and Scottish Government.

Robert Gatliff, Director Energy and Marine Geoscience, British Geological Survey

Robert joined the BGS in 1976 as a geologist/sedimentologist and worked in the Industrial Minerals Assessment Unit until 1981 when he transferred to Edinburgh and joined the Hydrocarbons Unit which provides the Government with independent geological advice on oil and gas exploration and production. He has contributed to major BGS publications on the Faroe-Shetland Basin, Rockall Basin, South West Approaches and the Central North Sea. He has international experience in South Pacific, Caspian and Africa. He was appointed Head of Marine & Petroleum Geology in 2003 and is now Director for Energy and Marine Geoscience research

in BGS, leading research teams on Regional Hydrocarbon Exploration (including the DECC/BGS Shale gas reports); Unconventional Hydrocarbons; Continental Margins; Advanced Geophysics; Carbon Capture & Storage; and Marine Geology, Geohazards and Engineering. Other positions include; Board Member of the Scottish Oil Club (2002-2011); member of the European Marine Data Expert Group (2008-2014); Member of the Geological Society Petroleum Group 1998-2004); Member of DEFRA Healthy & Biologically Diverse Seas Evidence Group (lead author for section of Charting Progress State of the Seas on the seabed).

Professor R. Stuart Haszeldine OBE, BSc (Edin), PhD (Strath), CGeol, FRSE, University of Edinburgh

Stuart Haszeldine has worked on coal, oil and gas deposits, with a wide interest in fossil fuels, radioactive waste disposal and environmental impact. He is Professor of Carbon Capture and Storage at the University of Edinburgh, and his current research examines geological storage of CO₂, in the context of climate change and changing energy use. This has rapidly developed as a topic of great scientific and political impact. He was previously first topic leader for the Carbon Management theme of the UK Energy Research Centre. He leads the UK's largest university research group for CO₂ storage and capture (Scottish Carbon Capture and Storage – SCCS) and is leader of the academic UK Carbon Capture and Storage Consortium. In 1999 he was awarded the Saltire Society and Royal Society of Edinburgh Science Prize for his work on radioactive waste disposal and hydrocarbon geology. In 2003 he was elected Fellow of the Royal Society of Edinburgh. In 2011 he was awarded the global William Smith Medal of the Geological Society for global excellence in Applied Geology.

In 2012 he was appointed OBE for services to climate change technologies. He has authored over 90 academic publications with a growing number of conference and technical reports on CCS.

Professor Kenneth Sorbie, Cairn Energy Professor of Petroleum Engineering, Heriot-Watt University

Ken Sorbie is the Cairn Energy Professor of Petroleum Engineering in the Institute of Petroleum Engineering (IPE) at Heriot-Watt University (HWU). He has a first degree in Chemistry from Strathclyde University and a DPhil in Theoretical Chemistry/Applied Mathematics from the University of Sussex. Following this, he did postdoctoral research at Cambridge University, working on theoretical aspects of semi-classical molecular quantum theory. He has worked in oil related research for over 33 years, firstly with the Department of Energy (now DECC) laboratory at AEE Winfrith where he led a group working on improved oil recovery, flow through porous media and reservoir simulation and, since 1988, at Heriot-Watt University. His currently research is in 3 main areas: (i) on the fundamentals of multi-phase flow through porous media, and (ii) on oilfield chemistry, particularly mineral scale formation and control, and (iii) in Enhanced Oil Recovery (EOR) both by gas injection (WAG) and chemical methods such a polymer, surfactant etc. Previously, Ken has also worked on several aspects of reservoir description, reservoir simulation and upscaling. He also teaches Reservoir Simulation on the HWU Masters course which he has taught previously in Edinburgh, at the HWU Centre in Tomsk, in Kazakhstan and elsewhere.

Since joining Heriot-Watt University in 1988, Ken and his close research collaborators have raised around \$30 million of research funding. He has published over 340 technical papers on his research and has consulted widely in the oil industry for over 35 industrial companies. He is

a regular visitor to companies and Research Institutes in Brazil, Abu Dhabi, Indonesia, Venezuela, Malaysia, Russia, Saudi Arabia, Kuwait, Italy, Norway, France, China and the US.

Ken was appointed as a Society of Petroleum Engineering (SPE) Distinguished Lecturer in 2000 – 2001 lecturing on Oilfield Scale Prevention and, in 2001, was elected a Fellow of the Royal Society of Edinburgh (FRSE). He was awarded the Society of Core Analysts (SCA) 2004 Technical Achievement Award, followed by the SPE IOR Pioneer Award for his contributions to Improved Oil Recovery in April 2008. Ken was nominated as the Cairn Energy Professor of Petroleum Engineering in 2008 and, since 2010, has been a Visiting Professor at the China University of Petroleum at Qindao, China. Recently, Ken was awarded a Lifetime Achievement Award from The Royal Society of Chemistry (Speciality Chemicals) for his contribution to Oilfield Chemistry research and teaching.

Professor Finlay Stuart, Professor of Isotope Geosciences, Scottish Universities Environmental Research Centre (SUERC)

Fin is Professor of Isotope Geosciences based at the Scottish Universities Environmental Research Centre in East Kilbride. His first degree was in Geology from University of Dundee, and was followed by a Ph.D. from Earth Science, University of Manchester (1992). He is the Head of Isotope Geochemistry at SUERC and maintains several laboratories. His research has largely focussed on gas geochemistry, concentrating on the use of the isotopic composition of the noble gases (He, Ne, Ar and Xe) to trace the origin and interaction history of modern and ancient fluids in the Earth's crust. His current research includes using geochemical techniques to track the fate of injected CO₂ in underground geological storage, and to identify the source of onshore natural gases.

Fin has received funding from the UK Research Councils to apply his knowledge to characterising the source of natural gases around sites of unconventional hydrocarbon extraction and to fingerprint gases produced by burning hydrocarbons prior to underground injection. His laboratory has undertaken consultancy work for BP and Total.

Professor Susan Waldron, Professor of Biogeochemistry, University of Glasgow

Professor Waldron holds a personal chair in biogeochemistry in the School of Geographical & Earth Sciences at Glasgow University. She has a longstanding interest in carbon cycling, firstly through environmental controls on biological production in methane (her PhD in this subject was funded by Greenpeace Environmental Trust), then as an energy flow in ecological studies, and now in budgetary constraints and process recycling in lotic and lentic systems. Previous research on the influence of peatland gas production on peatland hydrology, on field vegetation respiration studies and on freshwater invertebrate functional plasticity reflects the diversity of her interests in the carbon cycle. Her research focus now is on environmental resilience and adaptation of a landscape in energy provisioning, with significant activity on the C cycle response to hosting onshore renewable energy. Susan has received funding from the Natural Environment Research Council to apply her knowledge of isotope systematic to characterise the source of gases in the environment around sites of unconventional hydrocarbon extraction (2014-15 with Professor Stuart and Professor Haszeldine).

Professor Paul Younger FGS, C.Geol., FNEIMME, FICE, FICHEM, C.Sci., C.Eng., FEng. Rankine Chair of Engineering, Professor of Energy Engineering - University of Glasgow

Paul Younger has a diverse background, ranging from pure science (geology), water resources and environmental engineering (especially groundwater engineering), mining environmental engineering and energy engineering. Paul holds degrees from Newcastle University (BSc and PhD), and Oklahoma State University (MS), where he spent two years as a Harkness Fellow (1984-86), taking advantage of burgeoning activities in the then-National Centre for Groundwater Research and the EPA's RSKERL Lab in Ada. Paul has considerable industrial experience after working with Yorkshire Water, the National Rivers Authority, Centro Yunta (La Paz, Bolivia), NIREX, Northumbrian Water, several University start-up companies of which he is a Director (NuWater Ltd, Project Dewatering Ltd, Cluff Geothermal Ltd, Five-Quarter Energy Ltd) and various consultancy missions worldwide, for international bodies (e.g. World Bank) and charities (CAFOD and Amnesty International). Paul has had no involvement with the petroleum industry, other than an unpaid session advising BP on how they might diversify into geothermal energy.

Paul has direct first-hand experience of drilling and pumping fresh groundwater worldwide, and has drilled several deep geothermal boreholes, using technology adapted from the petroleum sector. He is thus uniquely placed to assess potential pollution impacts on groundwater, and to understand the capabilities and limitations of deep drilling technologies.

After spending 20 years at Newcastle University, Paul joined the University of Glasgow in August 2012. He is currently Chair of the Global Scientific Committee of the Planet Earth Institute, an international NGO which aims to promote South-South collaboration in science-based projects that further the cause of sustainable development in the countries of the Global South. He was elected a Fellow of the Royal Academy of Engineering (FEng) in 2007. He is the author of more than 350 publications, including the acclaimed books "Mine Water: Hydrology, pollution, Remediation" (Kluwer, 2002), "Groundwater in the Environment: An Introduction" (Wiley-Blackwell, 2007) and "Water: all that matters" (Hodder & Stoughton, 2012). His forthcoming book is "Energy: all that matters" (Hodder & Stoughton, 2014).

Professor James Curran MBE BA BSc PhD MInstP FRMetS CMet CPhys CEng

James has worked in environmental science and regulation for 30 years. He has undertaken studies in hydrometeorology, numerical modelling of marine waters, and water resources management, as well as a spell of direct regulatory enforcement with agricultural and industrial businesses. He has been a consultant to the Scottish Office and was for some years the Head of Science with the Scottish Environment Protection Agency and then Head of Environmental Strategy. In 2006 he co-founded and ran Entrading, a sustainable retailer. Later he took up a post, again with SEPA, first as Director Science and Strategy and now as Chief Executive. James was awarded MBE for services to the environment in 2007.

Professor Curran has no professional interests in, or connection to, the energy industries or coal, oil and gas in particular.

The Independent Expert Scientific Panel were grateful to receive presentations of evidence as part of their deliberations from the following:

- The Institute of Directors
- Brigantia Resources Ltd
- Friends of the Earth Scotland
- Scottish Wildlife Trust
- Reach Coal Seam Gas Ltd
- Scottish Government Planning Directorate

The Panel would also like to thank Dart Energy Ltd for allowing a site visit to their operations at Airth, near Falkirk.



**The Scottish
Government**
Riaghaltas na h-Alba

© Crown copyright 2014

ISBN: 978-1-78412-683-4

This document is also available on the Scottish Government website:
www.scotland.gov.uk

APS Group Scotland
DPPAS33661 (07/14)

w w w . s c o t l a n d . g o v . u k