Health & Fracking

The impacts & opportunity costs

health professionals for a
safer, fairer & better world

Background

Authors

This report has been written by Dr David McCoy and Dr Patrick Saunders.

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Section 3.2 has also benefited from a paper written upon the request of Medact by Dr Christophe McGlade and Professor Paul Ekins (UCL Institute for Sustainable Resources and UCL Energy Institute, University College London); Professor Michael Bradshaw (Warwick Business School, University of Warwick); and Professor Jim Watson (UK Energy Research Centre). It is available here.

The report has benefited from the expert advice of PSE Healthy Energy in the United States, notably from Dr Adam Law and Mr Jake Hays. PSE Healthy Energy is a leading inter-disciplinary research and policy institute focused on the adoption of evidence-based energy policy.

Further biographical information is provided in Appendix 1.

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This report builds on the knowledge, expertise and work of many scientists and individuals whose papers, reports and reviews are referenced in this report.

Declaration of interests

This report deals with a controversial topic. While fracking is an activity that can produce social and economic benefit; it also produces a variety of health hazards, and impacts negatively on the natural world. Inevitably there are questions about the distribution of risk and benefit across society as well as about trade-offs between short-term and long-term costs and benefits. These cannot solely be dealt with as a technical or scientific issue, and involve making judgements. Furthermore, as with many other areas of public policy, there are limits to data and knowledge.

For these reasons, it is important to state that Medact has received no dedicated funding to produce this report. Medact declares no conflict of interest with regard to any of the issues discussed in this report. It only declares an interest in promoting human and environmental health for the general good.

Disclaimer

The overall conclusions and opinions expressed in this report are the responsibility of the lead authors and do not necessarily reflect those of other contributors or their affiliated institutions.

Cover photo:
Cuadrilla drilling site, Balcombe, West Sussex, UK, 2013.

Contents

Glossary of Terms, Acronyms and Abbreviations

ATSDR: Agency for Toxic Substances and Disease Registry

Aquifer: underground water contained in permeable rock, gravel, sand or silt.

BGS: British Geological Survey

BTEX: Benzene, toluene, ethylbenzene, and xylenes

CCC: Committee on Climate Change

CCS: Carbon Capture and Storage. Process of trapping carbon dioxide produced by burning fossil fuels or other chemical or biological process and storing it in such a way that it is unable to affect the earth's atmosphere

CDC: Centers for Disease Control and Prevention

Chemical Scrubbing: Pollution control process for removing unwanted pollutants from a gas stream

CIEH: Chartered Institute of Environmental Health

CO_2: Carbon Dioxide

CO: Carbon Monoxide

DCLG: Department for Communities and Local Government

DECC: Department of Energy and Climate Change

DEFRA: Department for Environment, Food and Rural Affairs

DH: Department of Health

Disbond: Unplanned non-adhered or unbonded area within a bonded interface. Can be caused by adhesive or cohesive failure.

EA: Environment Agency

EAC: Environmental Audit Committee

EIA: Environmental Impact Assessment

EUR Estimated Ultimate Recovery. Sum of the proven reserves at a specific time and the cumulative production up to that time

Flowback: Fluids returned to the surface within a specified length of time following hydraulic fracturing

GHGs: Greenhouse Gases

Gt: Gigatons

HSE: Health and Safety Executive

HIA: Health Impact Assessment. A systematic process that uses an array of data sources and analytic methods, and considers input from stakeholders to determine the potential effects of a proposed policy, plan, programme, or project on the health of a population and the distribution of those effects

HVHF: High Volume Hydraulic Fracturing

IEA: International Energy Agency

LCA: Life Cycle Analysis. Technique to assess the environmental aspects and potential impacts associated with a product, process, or service compiling an inventory of relevant energy and material inputs and environmental releases and evaluating the associated potential environmental impacts

LNG: Liquefied Natural Gas

MPA: Minerals Planning Authority

NORM: Naturally-Occurring Radioactive Material

NOx Oxides of Nitrogen

NTDs Neural tube defects

O_3: Ozone

OUGO: Office of Unconventional Gas and Oil

PHE: Public Health England

PM: Particulate Matter

SCADA: Supervisory Control and Data Acquisition. An industrial computer system that monitors and controls a process

SGR: Scientists for Global Responsibility

SO_2: Sulphur Dioxide

VOCs: Volatile Organic Compounds

Wellhead: The structure over an oil or gas well

Wellpad: The area that has been cleared for a drilling rig to work on a plot of land designated for natural gas or oil extraction

Executive Summary

Background

The United Kingdom (UK) is presently set to expand 'hydraulic fracturing' of shale formations ('fracking') as a means of extracting unconventional gas. Proponents of fracking have argued that it can be conducted safely and will bring benefits in the form of: a) energy that is cleaner in climate terms than coal and oil; b) greater energy security; c) lower energy prices; d) more energy diversity and competition; and e) local employment and economic development. However, fracking has proven to be controversial and there are serious concerns about its safety and impact on the environment.

This report reviews fracking and its associated activities through a comprehensive public health lens. It examines the direct and immediate effects of fracking on health; the adequacy and capacity of the regulatory system; and the relationship between fracking and climate change.

It builds on a number of existing reviews of the evidence and interviews with various academics and experts (in the UK and abroad). Medact also requested short papers in particular subject areas to inform the production of this report. Given that much of the literature about fracking has been derived from experience in the United States (US), this report also highlights the specific features of the UK that need to be considered.

Fracking and its risks and threats

The word 'fracking' is used to denote high volume hydraulic fracturing (HVHF) and related activities. It describes a relatively new technology that is not to be confused with other forms of hydraulic fracturing that have been in use for decades. The term 'unconventional' describes the fact that the gas embedded in shale formations does not flow out as easily as in the case of conventional sources of gas. To extract unconventional gas, the shale needs to be fractured (or pulverised) by large volumes of fluid (water combined with various additives) injected into the ground under high pressures.

In doing so, fracking and its associated activities create multiple actual and potential sources of pollution. Leaks of gas can occur across the entire process of extraction, treatment, storage and transportation. There are also emissions from diesel engines, compressors and heavy transport vehicles; as well as the potential release of silica into the air. Oxides of nitrogen, hydrogen sulphide, formaldehyde, benzene, ethylene, toluene, particulate matter and ground-level ozone are among the more significant airborne health hazards. Surface and ground water can also be contaminated by gas, fracking fluid, or wastewater which consists of original fracking fluid combined with a range of new materials generated from underground (including lead, arsenic, chromium, cadmium; and naturally occurring radioactive material).

The health effects of these different hazards vary depending on the type and pattern of human exposure. But they include increased risks of cancer, respiratory disease and birth defects.

Shale gas development involves continuous activity conducted over a sustained period of time for the entire course of a day, seven days a week. Noise (from compressors, generators, drilling and heavy trucks); light pollution; bad odours; and heavy traffic can cause distress and negative health impacts on nearby communities, especially in the context of quiet rural and semi-rural areas.

The introduction of a temporary and intensive extractive industry will also disrupt and divide the social fabric of local communities, compounding both the mental and physical effects of other hazards. When conducted on an industrial scale, it will also alter the character and aesthetic of the local area and potentially affect wildlife and biodiversity as well.

Although fracking may bring local benefits in the form of new jobs and increased revenue, it can harm other economic sectors such as leisure and tourism; and affect the value of nearby homes. It is worth noting that employment generation associated with shale gas in the US has been over-stated and that initial economic booms often transform into long-term social and economic declines.

Assessing the level of risk and threat

There are now over 450 peer-reviewed publications in this field, consisting of studies, reviews and commentaries. A significant majority indicate potential risks or actual adverse health effects associated with shale gas development.

However, the precise level of risk to health cannot be known with certainty for a number of reasons. First, there is incomplete knowledge about the toxicity of a number of potential pollutants. Second, fracking itself is a new activity for which there are limited data and incomplete understanding. Third, the level of risk will depend on a range of geological, geographic, social, demographic, agricultural and economic factors that will vary from site to site.

The location, number and density of wellpads and boreholes; the size and proximity of surrounding communities; the presence and relative location of aquifers; the operating practices of fracking companies, including how they treat and dispose of waste; and the adequacy and effectiveness of the regulatory system are key variables. There are also features that are specific to shale formations. In the UK, shale formations are thick and geologically faulted, features that increase health and environmental risks associated with fracking when compared to the US.

While there is much uncertainty about risk, one can conclude that the regulatory system for fracking is presently incomplete and inadequately robust. Additionally, there are indications that the capacity of regulators is being further eroded by budget and staff cuts.

We can also say that if fracking is characterised by a high number and concentration of boreholes within relatively small rural and semi-rural areas that are well populated, the risk to public health would be considerable.

Climate change and greenhouse gas emissions

Shale gas extraction also has indirect health effects by virtue of its contribution to greenhouse gas emissions. The impact of climate change on health worldwide is already serious and threatens to be potentially catastrophic. Fracking threatens to perpetuate our reliance on fossil fuel and make it more difficult to meet our greenhouse gas (GHG) emission reduction targets.

The claim that shale gas is a clean source of energy that can aid the transition towards a low carbon energy system does not withstand scrutiny. Shale gas can only be considered as such, under very specific conditions. Among these are that shale gas would displace coal-powered electricity generation on a permanent and worldwide basis and do so within a relatively short timeframe. These conditions are not met in the UK. If anything, shale gas extraction will hinder the development of renewable and zero-carbon energy.

Adopting sensible and precautionary measures

The risks and serious nature of the hazards associated with fracking, coupled with the concerns and uncertainties about the regulatory system, indicate that shale gas development should be halted until a more detailed health and environmental impact assessment is undertaken.

Such an assessment has not been conducted yet, and would need to: account for all the potential risks to health, including their cumulative and compound effects on each other; be tailored to the specific geological, economic, environmental and social characteristics of the areas targeted for fracking; be based on projected levels of fracking at an industrial scale; and be conducted by a body that is entirely independent of the shale gas industry. The cost of an adequate regulatory system would also need to be factored in.

But given that shale gas may deepen the serious threats posed by climate change, there are compelling and important grounds to abandon the policy of shale gas development altogether.

Instead, we must embark upon a policy of encouraging faster development of clean energy and implementing plans to reduce energy consumption and ecological damage.

Chapter 1: Introduction

Why this report

The United Kingdom is presently set to to expand the high volume hydraulic fracturing of shale formations ('fracking') as a means of extracting unconventional gas.[1] This follows recent developments in shale gas development in the United States, and to a lesser extent in Canada and China.

The British Geological Survey (BGS) notes that the UK has abundant shales from which some (unknown) quantity of shale gas or oil may be extracted.[2] Potential areas include the north of England in and around the Pennines, the Weald Basin in Surrey and Sussex, and parts of Wales and Scotland.

Thus far, although onshore Petroleum Exploration and Development Licences have been awarded to various companies, only exploratory drilling has taken place in the UK. This includes the experience of test-fracking in Weeton, Lancashire in 2011 which was shut down following well damage caused by two earthquakes that had been induced by the fracking.

Public statements of support for fracking by the government, as well as a number of specific fiscal and legislative measures,[3] indicate a strong push to develop onshore shale gas production in the UK. It is argued that fracking can be conducted safely and bring various benefits in the form of: a) energy that is cleaner in climate terms than coal and oil; b) greater energy security; c) lower energy prices; d) more energy diversity and competition; and e) local employment and economic development.

A number of governmental reviews of fracking have been conducted, including a review of the potential health impacts of exposures to chemical and radioactive pollutants published by Public Health England (PHE) in November 2014. PHE concluded that: *"the currently available evidence indicates that the potential risks to public health from exposure to the emissions associated with shale gas extraction will be low if the operations are properly run and regulated"*.[4]

It went on to state that risks and reported problems associated with fracking *"are typically a result of operational failure and a poor regulatory environment"* and that *"good on-site management and appropriate regulation of all aspects including exploratory drilling, gas capture, use and storage of hydraulic fracturing fluid, and post-operations decommissioning are essential to minimise the risk to the environment and public health"*. The report indicated that shale gas developers and operators could be relied upon *"to satisfy the relevant regulators that their proposals and operations will minimise the potential for pollution and risks to public health"*.

However, while the PHE report comprehensively reviewed the literature on chemical and radioactive pollutants associated with fracking,[5] in its own words, *"other considerations, such as water sustainability,*

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1 Fracking can also be used to extract shale oil. This report only focuses on the plans to develop shale gas, and does not consider the potential for shale oil extraction..

2 British Geological Survey. How much shale do we have? bgs.ac.uk/research/energy/shaleGas/howMuch.html - URL no longer available

3 These include: a) 2013 Autumn Statement announcements to reduce the tax rate on profits derived from fracking from 62% to 30% and provide a tax allowance equal to 75% of the capital expenditure on projects; b) an announcement by the Prime Minster in January 2014 that local councils would be able to keep 100% of business rates collected from shale gas sites; c) 2014 Autumn Statement announcements of a £5 million fund to provide independent evidence to the public about the robustness of the existing regulatory regime and £31 million of funding to create sub-surface research test centres that would be applicable to a wide range of energy technologies including shale gas; and d) passage of an Infrastructure Act that includes provisions "to introduce a right to use deep-level land" for "petroleum or deep geothermal energy".

4 Kibble A, Cabianca T, Daraktchieva Z, Gooding T et al, 2014. Review of the Potential Public Health Impacts of Exposures to Chemical and Radioactive Pollutants as a Result of Shale Gas Extraction. Centre for Radiation, Chemical and Environmental Hazards, Public Health England. Available from: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/332837/PHE-CRCE-009_3-7-14.pdf

5 The PHE review only considered shale gas and did not review the immediate health impact of other extreme energy sources that are being considered in the UK such as 'tight oil and gas', 'coalbed methane' and 'underground coal gasification'.

noise, traffic (apart from vehicle exhaust emissions), odour, visual impact, occupational exposure and wider public health issues, have not been addressed". In addition, it did not assess the impacts of fracking on climate change. PHE's conclusions were also based on a questionable presumption that the regulatory framework for shale gas development would ensure that best operating practices would prevail.[6]

Accordingly, Medact has produced this report to provide a broader assessment of the potential impacts of fracking on health, including an assessment of the adequacy and capacity of the regulatory system. Importantly, it also considers the relationship between fracking and climate change. This report therefore provides a holistic, 'big picture' assessment of fracking and health.

Approach taken in producing this report

This report examines and builds on a number of reviews of the available scientific evidence on fracking, such as the one conducted by PHE.[7] Among these are the following:

- A Public Health Review of High Volume Hydraulic Fracturing for Shale Gas Development conducted by the New York State Department of Health (December 2014). Available from: http://www.health.ny.gov/press/reports/docs/high_volume_hydraulic_fracturing.pdf.
- Cherry J, Ben-Eli M, Bharadwaj L, Chalaturnyk R et al, 2014. Environmental Impacts of Shale Gas Extraction in Canada: the Expert Panel on Harnessing Science and Technology to Understand the Environmental Impacts of Shale Gas Extraction. Retrieved from http://bit.ly/1nNicuf
- Broomfield M, 2012. Support to the Identification of Potential Risks for the Environment and Human Health Arising from Hydrocarbons Operations Involving Hydraulic Fracturing in Europe. European Commission, DG Environment publication 07.0307/ENV.C.1/2011/604781/ENV.F1. Retrieved from ec.europa.eu/environment/integration/energy/pdf/fracking%20study.pdf
- Wheeler D, Atherton F, Bradfield M, Christmas K et al, 2014. Report of the Nova Scotia Independent Panel on Hydraulic Fracturing. Available from: http://energy.novascotia.ca/sites/default/files/Report%20of%20the%20Nova%20Scotia%20Independent%20Panel%20on%20Hydraulic%20Fracturing.pdf
- Adgate JL, Goldstein BD, McKenzie LM, 2014. Potential public health hazards, exposures and health effects from unconventional natural gas development. *Environ. Sci. Technol.* 48 (15): 8307–8320.
- Shonkoff SB, Hays J, Finkel ML, 2014. Environmental public health dimensions of shale and tight gas development. *Environ. Health Perspect.* 122 (8): 787-795.
- Werner AK, Vink S, Watt K, Jagals P, 2015. Environmental health impacts of unconventional natural gas development: a review of the current strength of evidence. *Sci. Total Environ.* 505: 1127–1141.
- University of Maryland, School of Public Health (2014). Potential Public Health Impacts of Natural Gas Development and Production in the Marcellus Shale in Western Maryland.

As well as reviewing published literature, Medact requested short papers from relevant experts in particular subject areas and interviewed various other academics and experts.

6 Law A, Hays J, Shonkoff SB, Finkel ML, 2014. Public Health England's draft report on shale gas extraction: mistaking best practices for actual practices. *Brit Med J.* 348:g2728. Doi: 10.1136/bmj.g2728.

7 All web links in the footnotes were checked on March 22nd, 2015.

Chapter 2: High Volume Hydraulic Fracturing

The term 'fracking' is used in this report to denote high volume hydraulic fracturing (HVHF) *and related activities*. This is a relatively new technology and is not to be confused with other forms of hydraulic fracturing which have been around for several decades. HVHF, the technique that would be needed for UK shale gas extraction, employs much higher volumes and pressures of liquid and is associated with the use of various chemicals. For instance, while some forms of hydraulic fracturing may only require up to 300,000 gallons of fracturing fluid per well, HVHF requires between two and five million gallons per well.[8] HVHF also requires a heavier use of ancillary infrastructure.

The term unconventional is used to describe the fact that the gas embedded in the shale does not flow out as easily as in the case of conventional sources of gas. It is more difficult to extract, requiring deep shale rock formations to be pulverised and fractured by hydraulically pressurised fluid injected into the ground. To do this, a well head is first established and a vertical borehole is drilled down to the shale formation. Horizontal drilling is also conducted, so that each well head, with its vertical borehole, will have a number of associated lateral sections.[9] Aquifers are given some protection by the use of triple-layered steel casings which are cemented into place to reduce the risk of fluids or gases migrating out of the borehole.[10]

Vertical drilling may go down to around ten thousand feet below the surface. Lateral sections can extend up to 20,000 feet from the vertical borehole, with typical extensions being in the order of 5,000 to 15,000 feet. A perforation gun is then run into the well and punches holes into the surrounding rock using explosive charges. The well is then cleared of debris in preparation for the hydraulic fracturing. The millions of gallons of fluid are injected into boreholes by high-volume, high-pressure pumps on the surface.

The majority of fractures are only a few micrometres in width and usually limited in length to a few tens of metres. Fracking can, in certain circumstances, lead to fracture propagation to the surface or near-surface, especially if it takes place at relatively shallow depths. When shale formations are deep in the ground, there is less of a threat to aquifers (that are less deep in the ground). However, the fracking of shale formations that are geologically faulted may risk aquifers even if they are deep in the ground.

Various chemicals and compounds have often been added to water to create hydraulic fracturing fluid. These can include silica (sand) used to prop open the shale fractures; biocides to prevent bacterial growth; surfactants which reduce surface tension to aid fluid recovery; polymers to reduce friction; and chemicals to inhibit corrosion of metal pipes. Chemicals are said to account for between 0.5 - 1% of the fluid mixture.[11] However, the composition of fracking fluid will vary depending on the type of rock being fractured and other factors.

8 United States Environmental Protection Agency, 2012. Study of the Potential Impacts of Hydraulic Fracturing on Drinking Water Resources: Progress Report. Available from: epa.gov/sites/production/files/documents/hf-report20121214.pdf (URL no longer available)

9 Boreholes are usually only vertical in the 'exploratory phase'. However, the next set of exploratory wells planned for the Fylde coast near Lytham St Annes are set to contain lateral sections.

10 There are other protections offered to aquifers by the regulatory system such as the prohibition of fracking in certain sensitive areas (source protection zone 1).

11 International Association of Oil and Gas Producers, 2013. Shale Gas and Hydraulic Fracturing, Ensuring a Safe, Clean, Secure and Competitive Energy Source for Europe. Available from: ngsfacts.org/files/9513/7121/9522/FAQs_updated.pdf (URL no longer available)

The volume of fluid that stays in the ground varies.[12] Anything between 10 and 90% of the fracking fluid is recovered at the surface as 'flowback' depending on the characteristics of the shale. A typical recovery rate would be about 35% which implies a large volume of flowback needing to be managed on the surface.[13] However, flowback is different in nature and composition from the original fracking fluid that was injected into borehole, containing a range of new materials generated from underground, including some that are toxic and hazardous. These can include various waste gases; heavy metals such as lead, arsenic, chromium, cadmium; and naturally occurring radioactive material (NORM).[14] There are various options for the treatment and disposal of flowback, including on- or off-site treatment; and either disposal or reuse as fracking fluid.[15 16]

There will be various impurities and contaminants contained within the recovered gas as well. These have to be removed before the gas can be used commercially. This can be done through 'chemical scrubbing' or by 'flaring' (a process in which 'dirty gas' is simply burnt off). Clean gas can then be carried away by installation of a new pipe infrastructure linking wellpads to the national gas grid, or compressed, stored and then transported.

The process of fracking and its associated activities can create multiple sources of potential pollution. Emissions can occur across the entire process of gas extraction, treatment, storage and transportation; and can arise from the ground and wells; from pumps, flanges, valves and pipe connectors; and from the practice of flaring. Some emissions are referred to as 'fugitive emissions' – these are unintended or irregular and may include methane and various other volatile organic compounds (VOCs) such as benzene, formaldehyde and toluene as well as radon and oxides of nitrogen (NOx).

Emissions from diesel engines, compressors and heavy transport vehicles include particulate matter (PM), ground-level ozone (a pollutant in its own right but also a key constituent of smog), carbon monoxide (CO), NOx, sulphur dioxide (SO_2) and carbon dioxide (CO_2). Diesel exhaust emissions are a particular health hazard[17] when large numbers of truck journeys are required.[18 19] Leakage, spillage and improper discharge of flowback and other process residues (e.g. cutting fluids, mud, scales and sludges) are other possible source of pollution above ground.

Underground, there can be contamination of aquifers with methane and other gases in areas adjacent to fracking during injection and flowback, and stranded fracking fluids (those remaining underground) can also migrate into surrounding areas. Well integrity is important- loss of integrity may result in leaks of gas and liquid. Once wells are drilled and hydraulically fractured they remain in the ground indefinitely and, even if plugged, may continue to leak (gas and liquid) for up to thirty years after they have been abandoned.[20]

12 Shonkoff SB, Hays J, Finkel ML, 2014. Environmental public health dimensions of shale and tight gas development. *Environ. Health Perspect.* 122 (8): 787-795

13 The Institution of Civil Engineers estimate that a single well could produce between 7,500 to 18,750m3 of flowback annually. See written submission to Environmental Audit Committee: Environmental Risks of Fracking Enquiry (FRA070), para 2.1.

14 Environmental Agency, 2011, Shale Gas, North West – Monitoring of Flowback Water fraw.org.uk/files/extreme/envage_flowback_2011.pdf (URL no longer available)

15 Rahm BG, Bates JT, Bertoia LR, Galford AE *et al*, 2013. Wastewater management and Marcellus Shale gas development: Trends, drivers, and planning implications. Journal of Environmental Management, 20: 105–113. DOI:1.1016/j.jenvman.2013.02.029.

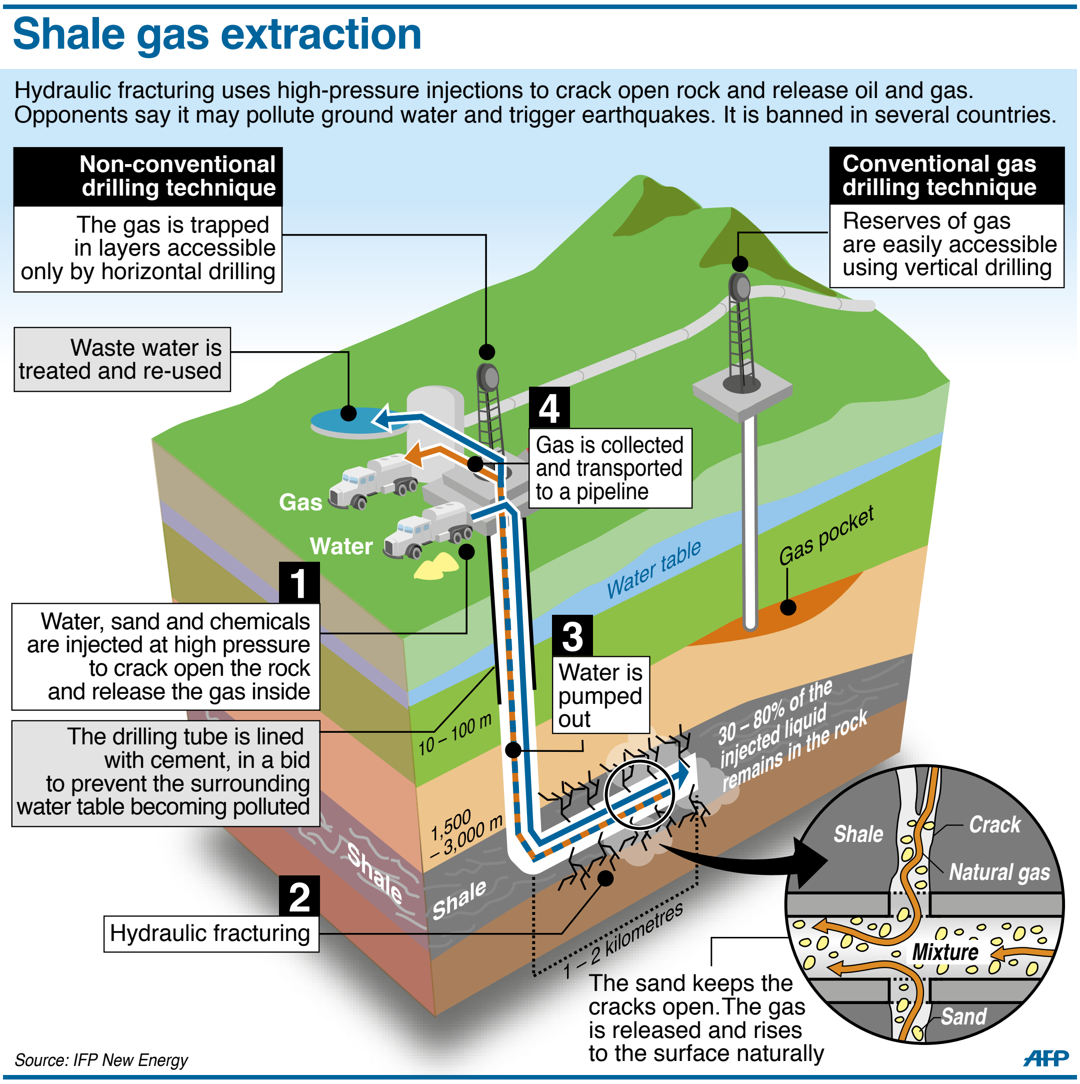
16 Fakhru'l-Razi A, Pendashteh A, Abdullah LC, Biak DRA, Madaeni SS *and* Abidin ZZ, 2009. Review of technologies for oil and gas produced water treatment. Journal of Hazardous Materials, 170: 530–551

17 Krivoshto I, Richards J, Albertson T, Derlet R, 2008. The toxicity of diesel exhaust: implications for primary care. *J Am Board of Fam Med*, 21(1): 55-62. Doi: 10.3122/jabfm.2008.01.070139.

18 Penning T, Breysse P, Gray K et al, 2014. Environmental Health Research Recommendations from the Inter-Environmental Health Sciences Core Center Working Group on Unconventional Natural Gas Drilling Operations. *Environ Health Perspect* Vol 122 (11): 1155-1159. Doi: 10.1289/ehp.1408207

19 McCawley M, 2013. Air, Noise, and Light Monitoring Results for Assessing Environmental Impacts of Horizontal Gas Well Drilling Operations. West Virginia University School of Public Health, Morgantown, WV. Retrieved from ri.org/wp-content/uploads/2013/10/a-n-l-final-report-for-web.pdf (URL no longer available)

20 Kang M, Kanno CM, Reid MC, Zhang X et al, 2014. Direct measurements of methane emissions from abandoned oil and gas wells in Pennsylvania. PNAS vol. 111 no. 51: 18173–18177, doi: 10.1073/pnas.1408315111



Note: This diagram is included for illustrative purposes only. It provides a broad visual depiction of fracking but is not a precise representation of shale gas production in the UK. Features shown in this diagram that do not apply to the UK include the depth and thickness of shale; the number of boreholes; and the way waste water is shown to be collected, treated and re-used on site. See chapter 4 for additional material.

Studies indicate that between 6% and 75% of wells experience loss of zonal isolation or structural integrity failures, and that the unconventional wells used in fracking, fail at a higher rate[21-24] Loss to the structural integrity of wells is common and increases as wells age and as steel corrodes and cement shrinks, cracks, or disbonds from the casing and rock.

21 Ingraffea AR, Wells MT, Santoro RL, Shonkoff SBC, 2014. Assessment and risk analysis of casing and cement impairment in oil and gas wells in Pennsylvania, 2000-2012. PNAS vol 111 (30): 10955-60. Available at: pnas.org/content/111/30/10955.full.pdf (URL no longer available)

22 Davies RJ, Almond S, Ward RS, Jackson RB et al, 2014. Oil and gas wells and their integrity: Implications for shale and unconventional resource exploitation. Marine and Petroleum Geology 56 (2014) 239e254

23 Jackson R, 2014. The integrity of oil and gas wells. PNAS. 111 (30): 10902-10903. Doi: 10.1073/pnas.1410786111.

24 Watson T and Bachu S, 2009. Evaluation of the potential for gas and CO2 leakage along wellbores. SPE Drilling & Completion. 24 (1):115-126. Doi: 10.2118/106817-MS. Available from: http://www.researchgate.net/publication/254526287_Evaluation_of_the_ Potential_for_Gas_and_CO2_Leakage_Along_Wellbores

Gas well drilling rigs in USA.

Les Stone

Les Stone

Chapter 3: Assessing the Health Impacts of Fracking

This chapter comprises two sections:

- The direct and immediate impacts of fracking, covering the potential risks and hazards associated with environmental pollution and contamination, as well as noise, light pollution, traffic and various other social, environmental and economic effects
- The impact of fracking on greenhouse gas emissions and climate change

3.1 The direct and immediate health impacts of fracking

As described in Chapter 2, fracking for shale gas is an inherently risky activity that generates various health hazards. Some degree of environmental pollution is inevitable. Among the important toxic pollutants are benzene (an example of a 'non-threshold' toxin for which there are no actual safe levels of exposure), formaldehyde, heavy metals, NORM, radon and methane (see supplementary briefing paper *Additional information about potential pollutants and toxins* for more detail).

Certain aspects of fracking (e.g. loss of wellbore structural integrity due to ageing and leaks from ancillary infrastructure) are impossible to eradicate completely even with the adoption of best practice. Accidents do happen, and some people will be negatively affected by some of the social and economic effects of fracking.

The question is therefore whether risks can be mitigated and reduced to an acceptable level; and whether harms and benefits are distributed in a fair manner. When considering this, three things must be noted.

First, we have incomplete knowledge. While many of the potential pollutants associated with fracking are known toxins, not all of them have been completely studied. Others have not been studied at all. Furthermore, while safety standards have been established for some pollutants on an individual basis, few take account of any 'cocktail' effects resulting from simultaneous exposure to multiple hazards. Our incomplete knowledge is also caused by a lack of information about fracking operations due to inadequate regulation and the use by the gas industry of non-disclosure agreements that have hindered public interest monitoring and evaluation efforts in the US.[25 26 27]

Secondly, fracking is a relatively new activity. The geologies of shale formations are more poorly understood compared to conventional hydrocarbon reservoirs; and although the scientific literature is rapidly expanding, there are still few robust and long-standing 'exposure studies' of the impact of fracking on health. According to the Council of Canadian Academies, evidence about the longer term cumulative impacts of fracking are generally not yet available and difficult to predict reliably.[28 29]

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25 Maule A, Makey C, Benson E, Burrows I and Scammel M, 2013. Disclosure of hydraulic fracturing fluid chemical additives: analysis of regulations. New Solut. 23(1): 167–87. PM. 23552653.

26 https://www.guernicamag.com/daily/naveena-sadasivam-in-fracking-fight-a-worry-about-how-best-to-measure-health-threats/

27 http://www.businessweek.com/news/2013-06-06/drillers-silence-u-dot-s-dot-water-complaints-with-sealed-settlements

28 Council of Canadian Academies, 2014. Environmental Impacts of Shale Gas Extraction in Canada: the Expert Panel on Harnessing Science and Technology to Understand the Environmental Impacts of Shale Gas Extraction Retrieved from: http://bit.ly/1nNicuf

29 The caution of the Council of Canadian Academies is shared by the US Centers for Disease Control and Prevention and US Agency for Toxic Substances and Disease Registry (ATSDR) which concluded: "CDC and ATSDR do not have enough information to say with certainty whether natural gas extraction and production activities including hydraulic fracturing pose a threat to public health. We believe that further study is warranted to fully understand potential public health impacts." See here: http://www.cdc.gov/media/releases/2012/s0503_hydraulic_fracturing.html

Thirdly, human exposure to the risks and hazards associated with fracking will vary from site to site depending on a host of geological, social, demographic, agricultural and economic factors. This includes the size, number and proximity of communities to fracking sites; the number and density of wellpads and boreholes; and the operating practices of fracking companies, including their adherence to safety standards and best practices. In addition, the impact of exposure to risks and hazards will vary amongst individuals due to the distribution of other factors that render them vulnerable such as deprivation, poor diet and pre-existing health conditions. This means that health impacts will be unevenly and often unfairly distributed between and within local communities.

For these reasons, although one can state categorically that fracking poses threats to human health, the precise level of risk cannot be known with certainty. Assessing the level of risk requires careful judgement based on the available evidence and an appropriate attitude towards the precautionary principle, whilst considering contextual factors *and* the potential benefits of fracking.

Air pollution

Exposure to hazardous airborne pollutants will be influenced by, among other things, differences in the underlying geology and maturity of the shale; the number of wells and boreholes in proximity to communities; topographical features and meteorological conditions that affect the dispersion of pollutants; phase of fracking (different types and amounts of pollutants are emitted during different phases); and operational practices at the extraction site.

While the impact of emissions from individual fracking wells may be relatively small and intermittent (and not unlike some other industrial activities), the cumulative impact of many wells can lead to a high level of risk to human health. There are now a number of studies and reviews highlighting the health and air quality risks associated with fracking and natural gas development activities.[30-36]

Emissions of NOx, hydrogen sulphide, formaldehyde, benzene, PM, and ozone (O_3) are the more significant airborne hazards associated with fracking. Exposure to diesel exhaust fumes or to silica (used in fracking fluid to 'prop open' the shale fractures) may also cause various conditions and diseases. As well as catalysing development of ground level ozone, methane can combine with PM to form gas field haze which is linked to respiratory disease and other harms.

The health effects of these different hazards are varied, depending on the nature, type and pattern of exposure. One important health impact assessment from the US indicated that sub-chronic exposure to chemical emissions, especially during well development and completion phases was the main concern for residents within a half mile radius of the well pad.[37] Some potential hazards, such as benzene, are known carcinogens; while others increase the risk of birth defects[38] or cause chronic respiratory disease.

30 Colborn T, Schultz K, Herrick L, Kwiatkowski C. An exploratory study of air quality near natural gas operations. Hum Ecol Risk Assess 2014; 1: 86-105.doi: 10.1080/10807039.2012.749447.

31 Kemball-Cook S, Bar-Ilan A, Grant J, Parker L et al, 2010. Ozone impacts of natural gas development in the Haynesville shale. Environ. Sci. Technol. 44 (24): 9357–9363. Doi: 10.1021/es1021137

32 Edwards P, Brown S, Roberts J, Ahmadov R et al, 2014. High winter ozone pollution from carbonyl photolysis in an oil and gas basin. Nature. 514: 351–354. Doi: 10.1038/nature13767.

33 Moore CW, Zielinska B et al, 2014. Air impacts of increased natural gas acquisition, processing, and use: a critical review. Environ Sci Technol. 48 (15): 8349-8359. Doi: 10.102/es4053472.

34 McKenzie LM, Witter RZ, et al (2012). Human health risk assessment of air emissions from development of unconventional natural gas resources. Sci Total Environ 424: 79–87.

35 Roy A, Adams P, Robinson A. Air pollutant emissions from the development, production and processing of Marcellus Shale natural gas. J Air Waste Manage Assoc 2014; 64: 19–37.

36 Macey et al. 2014 Air concentrations of volatile compounds near oil and gas production: a community-based exploratory study. Environmental Health 2014, 13:82 doi:10.1186/1476-069X-13-82

37 McKenzie L, Witter R, Newman L, Adgate J, 2012. Human health risk assessment of air emissions from development of unconventional natural gas resources. Sci Total Environ. 424: 79–87. Doi: 10.1016/j.scitotenv.2012.02.018.

38 McKenzie L, Guo R, Witter R, Savitz D et al, 2014. Birth outcomes and maternal residential proximity to natural gas development in rural Colorado. Environ Health Perspect. 122 (9). Doi:10.1289/ehp.1306722

Contamination of ground and surface water

Various studies and reviews have noted that fracking for shale gas (as well as other forms of onshore gas extraction) can lead to ground and surface water pollution.[39-51] Potential pollutants include methane itself; fracking fluid; or various compounds that have been generated from underground including lead, arsenic, chromium, cadmium; NORM and radon.

Evidence from the US indicates that failure of oil and gas well cement and casing barriers is the most common cause; followed by surface spills or the accidental release of fracking fluid or flowback. One review of 43 incidents of environmental pollution related to natural gas operations (including shale) found that almost 50% were related to the contamination of groundwater as a result of drilling operations with the most common cause being inadequate cementing or casing into wellbores, and the second most common cause (33%) being surface spills due to leaks, overflowing pits and failures of pit linings.[52]

As with air pollution, the risk of water pollution and its impact on human and ecological health is dependent on many variables. These include geological factors related to the shale formation itself; the nearby presence of aquifers; the number of boreholes and intensity of fracking; the policy and practices for the management, treatment and disposal of flowback; and the extent to which communities source their drinking water from public utilities with water treatment facilities and good quality controls.

For example, the risk of contaminants reaching underground sources of drinking water through fractures is considered remote where there is a separating impermeable layer of at least 600m between the drinking water sources and the production zone.[53] Fracking that takes place at relatively shallow depths is a greater risk to water contamination than if it takes place at deeper levels.[54] PHE considers

39 House of Commons Energy and Climate Change Committee, 2011. Shale Gas: Fifth Report of Session 2010–12. Available from: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/79187/scishalegasvol2.pdf.

40 Royal Society and Royal Academy of Engineering, 2012. Shale Gas Extraction in the UK: A Review of Hydraulic Fracturing. Available from: https://royalsociety.org/~/media/policy/projects/shale-gas-extraction/2012-06-28-shale-gas.pdf.

41 Lechtenböhmer S, Altmann M, Capito S, Matra Z et al., 2011. Impacts of shale gas and shale oil extraction on the environment and human health. European Parliament, Policy Department A: Economic and Scientific Policy, Available from; http://www.europarl.europa.eu/document/activities/cont/201107/20110715ATT24183/20110715ATT24183EN.pdf.

42 Osborn S, Vengosh A, Warner N, Jackson R, 2011. Methane contamination of drinking water accompanying gas-well drilling and hydraulic fracturing. PNAS. 108 (20: 8172–8176. Doi: 10.1073/pnas.1100682108.

43 Fontenot B, Hunt L, Hildenbrand Z, Carlton Jr D, et al, 2013. An evaluation of water quality in private drinking water wells near natural gas extraction sites in the Barnett shale formation. Environ. Sci. Technol. 47 (17: 10032–10040. Doi: 10.1021/es4011724.

44 Gross S, Avens H, Banducci A, Sahmel J et al, 2013. Analysis of BTEX groundwater concentrations from surface spills associated with hydraulic fracturing operations. J. Air Waste Manag. Assoc. 63 (4: 424–432. Doi: 10.1080/10962247.2012.759166.

45 Jackson R, Vengosh A, Darrah T, Warner N et al, 2013. Increased stray gas abundance in a subset of drinking water wells near Marcellus shale gas extraction. PNAS. 110 (28: 11250-11255. Doi: 10.1073/PNAS.1221635110.

46 Kassotis C, Tillitt D, Davis J, Hormann A, Nagel S, 2013. Estrogen and androgen receptor activities of hydraulic fracturing chemicals and surface and ground water in a drilling-dense region. Endocrinology. 155 (3: 897–907. Doi: 10.1210/en.2013-1697.

47 Bamberger M, Oswald R, 2012. Impacts of gas drilling on human and animal health. New Solut. 22 (1: 51-77. Doi: 10.2190/NS.22.1.e

48 Council of Canadian Academies, 2014. Environmental Impacts of Shale Gas Extraction in Canada: the Expert Panel on Harnessing Science and Technology to Understand the Environmental Impacts of Shale Gas Extraction. Retrieved from http://bit.ly/1nNicuf

49 Davies R, Almond S, Ward R, Jackson R et al, 2014. Oil and gas wells and their integrity: Implications for shale and unconventional resource exploitation. Mar. Pet. Geol. 56: 239–254.
Doi: 10.1016/j.marpetgeo.2014.03.001.

50 Dusseault M, Jackson R, MacDonald D, 2014. Towards a Road Map for Mitigating the Rates and Occurrences of Long-Term Wellbore Leakage. Geofirma Engineering Ltd. Available from: http://geofirma.com/wp-content/uploads/2015/03/Wellbore_Leakage_Study-compressed.pdf.

51 Ingraffea A, Wells M, Santoro R, Shonkoff S, 2014. Assessment and risk analysis of casing and cement impairment in oil and gas wells in Pennsylvania, 2000–2012. PNAS. 111 (30): 10955-10960. Doi: 10.1073/pnas.1323422111.

52 Massachusetts Institute of Technology, 2011. Study on the Future of Natural Gas. MIT Energy Initiative. Available at: mitei.mit. edu/system/files/NaturalGas_Report.pdf

53 PHE quoting AEA Technology, 2012a

54 Davies RJ, Almond S, Ward RS, Jackson RB et al, 2014. Oil and gas wells and their integrity: Implications for shale and unconventional resource exploitation. Marine and Petroleum Geology 56 (2014239e254

there is little concern from a groundwater contamination perspective as shale is relatively deep[55] but also notes that this may not be true at shallower depths. PHE also note that cross-connections between wells, including abandoned wells, could provide migratory pathways for gas and fluids.[56]

Traffic, dust, noise, odours, un-natural light and other nuisances

Shale gas development involves continuous activity conducted over a sustained period of time (this can vary considerably, but is often several years) over the entire course of a day, seven days a week.[57] The noise of compressors, generators and drilling; extensive truck movements; intrusive un-natural lighting overnight; and the release of bad smelling chemicals, can have significant negative health and wellbeing impacts on nearby communities, especially in the context of quiet rural and semi-rural areas that are also relatively densely populated.[58]

The amount of truck-heavy traffic required to build the wellpad and its surrounding infrastructure (e.g. offices, generators, compressors and tanks), drill the boreholes, and transport fluid, silica and various other materials is considerable. Estimates of the amount of traffic involved vary, with the critical factors being: the number of boreholes; whether water is piped or trucked in; and the volume of flowback needing to be transported away. The Institution of Civil Engineers estimated that a single well might require between 500 and 1,250 HGV lorry movements.[59] The Royal Society for the Protection of Birds estimated a figure of between 4,300 and 6,600 truck trips per well pad.[60] If a well pad were to generate as many as 40 boreholes, the number of truck movements could be of the order of 34,000 movements on and off a pad (over the typical two year lifetime of a well, but with a concentrated period of about six months).

Potential adverse impacts from truck traffic include congestion; road traffic accidents (with potential spills of hazardous materials); as well as damage to roads, bridges and other infrastructure. One study from the US reported that automobile and truck accident rates were between 15% and 65% higher in counties with fracking compared to those without, including an associated increase in traffic fatalities.[61]

Noise, smells and intrusive lighting are well recognised as health hazards and potentially serious interferences to normal day-to-day living.[62] [63] [64] The stress that will be imposed upon individuals and communities is hard to predict or generalise, and will critically depend on the proximity and size of surrounding populations. It constitutes a significant form of ill health in its own right, and is a co-factor in the genesis of a range of other diseases and illnesses.[65] [66]

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55 PHE state that induced vertical fracture heights "do not exceed 'tens to hundreds of feet', and are therefore unlikely to be a concern from a groundwater contamination perspective" (PHE quoting Fisher and Warpinski, 2012 However, this is only true in areas with no pre-existing faults extending to the near-surface.

56 PHE citing Jackson RE et al, 2013

57 The typical lifetime for a well is variable, ranging from about two to five years depending on how much the shale is re-worked and the well re-fracked.

58 McCawley M, 2013. Air, Noise, and Light Monitoring Results for Assessing Environmental Impacts of Horizontal Gas Well Drilling Operations (ETD10 Project. http://wvwri.org/wp-content/uploads/2013/10/a-n-l-final-report-for-web.pdf

59 Institution of Civil Engineers. Written Submission, Environmental Audit Committee: Environmental Risks of Fracking Enquiry (FRA070), para 2.1

60 Royal Society for the Protection of Birds. Written Submission to Environmental Audit Committee: Environmental Risks of Fracking Enquiry (FRA015, para 3.6

61 Graham J, Irving J, Tang X, Sellers S, et al. (2015. Increased Traffic Accident Rates Associated with Shale Gas Drilling in Pennsylvania. Accident Analysis and Prevention, 74:203–209.

62 https://www.gov.uk/statutory-nuisance

63 WHO/European Commission. Burden of disease from environmental noise. Quantification of healthy life years lost in Europe. The WHO European Centre for Environment and Health, Bonn Office, WHO Regional Office for Europe . ISBN: 978 92 890 0229 5 2011

64 http://ec.europa.eu/health/scientific_committees/opinions_layman/artificial-light/en/l-2/4-effects-health.htm#1

65 As an example of how stress can be formed from the cumulative effects of multiple hazards and nuisances see: Battlement Mesa Health Impacts Assessment (Colorado, USA). Available at garfield-county.com/environmental-health/battlement-mesa-health-impact-assessment-ehms.aspx - URL no longer available

66 Gee GC, Payne-Sturges DC, 2004. Environmental Health Disparities: A Framework Integrating Psychosocial and Environmental Concepts. Environ Health Perspect. 112(17: 1645–1653

Social, environmental and economic effects

Other effects of fracking that can impact negatively on health, particularly through the pathway of stress, include disruption to the social fabric of local communities, impacts on other economic activity, ecosystem damage and spoilage of the natural environment.

Shale gas development, conducted on an industrial scale, is a spatially intense activity that would alter the character and aesthetic of several rural and semi-rural areas and affect wildlife and biodiversity. The literature assessing the ecological impacts of shale gas development is growing.[67-76] Adverse effects on agro-ecosystems and animal husbandry have also been identified, although the evidence-base is more limited.[77]

The economic impact of losing green space and 'ecosystem services', including damage to leisure and tourism, needs to be considered. This is rarely or incompletely assessed,[78] although the health benefit of the availability and access to green spaces has been documented.[79 80] In addition to economic considerations, many people believe that the natural integrity and beauty of a landscape contains an intrinsic value which should be celebrated and preserved. This is a consideration with all types of energy development (e.g. wind and hydro power) and careful assessment of both the costs and benefits is always needed.[81]

The introduction of temporary but intensive extractive industries into an area can disrupt and change the local social and economic fabric in many ways.[82] While this can include benefits in the form of new jobs and increased local revenue, it can also bring a variety of social and public health harms. This has

67 Jones NF and Pejchar L, 2013. Comparing the ecological impacts of wind and oil & gas development: a landscape scale assessment. PLoS ONE 8 (11), e81391.

68 Jones I, Bull J, Milner-Gulland E, Esipov A, Suttle K, 2014. Quantifying habitat impacts of natural gas infrastructure to facilitate biodiversity offsetting. Ecol. Evol. 4 (1): 79–90. Doi: 10.1002.ece3.884.

69 Souther S, Tingley M, Popescu V, Hayman et al, 2014. Biotic impacts of energy development from shale: research priorities and knowledge gaps. Front. Ecol. Environ. 12 (6): 330–338. Doi: 10.1890/130324.

70 Hamilton L, Dale B, Paszkowski C, 2011. Effects of disturbance associated with natural gas extraction on the occurrence of three grassland songbirds. Avian Conserv.Ecol. 6 (1): 7. Doi: 10.5751:ACE-00458-060107.

71 Papoulias D, Velasco A, 2013. Histopathological analysis of fish from Acorn Fork Creek, Kentucky, exposed to hydraulic fracturing fluid releases. Southeast. Nat. 12 (sp4): 92–111.Doi: 10.1656/0(!.012s413.

72 Weltman-Fahs M, Taylor J, 2013. Hydraulic fracturing and brook trout habitat in the Marcellus Shale region: potential impacts and research needs. Fisheries. 38 (1): 4–15. Doi: 10.1080/03632415.2013.750112.

73 Adams M, 2011. Land application of hydrofracturing fluids damages a deciduous forest stand in West Virginia. J. Environ. Qual. 40 (4): 1340–1344. Doi:10.2134/jeq2010.0504.

74 Brittingham M, Maloney K, Farag A, Harper D, Bowen Z, 2014. Ecological risks of shale oil and gas development to wildlife, aquatic resources and their habitats. Environ. Sci. Technol. 48 (19):11034–11047. Doi: 10.1021/es5020482.

75 Racicot A, Babin-Roussel V, Dauphinais J, Joly J-S et al, 2014. A framework to predict the impacts of shale gas infrastructures on the forest fragmentation of an agroforest region. Environ. Manag. 53 (5): 1023–1033. Doi: 10.1007/s00267-014-0250-x.

76 Kiviat E, 2013. Risks to biodiversity from hydraulic fracturing for natural gas in the Marcellus and Utica shales. Ann N Y Acad Sci. 1286: 1–14. Doi: 10.1111/nyas.12146.

77 Bamberger M, Oswald RE, 2012. Impacts of Gas Drilling on Human and Animal Health. New Solutions 22, 51–77.

78 Finkel ML, Hays J, 2013. The implications of unconventional drilling for natural gas: a global public health concern. Public Health 127 (10), 889–893.

79 Mitchell R, Popham F, 2008. Effect of exposure to natural environment on health inequalities: an observational population study. The Lancet. 372: 1655-1660. Doi: 10.10166/50140-6736(08)61689-x.

80 CABE, 2010. Community green: using local spaces to tackle inequality and improve health. London. Available from: http://www.openspace.eca.ed.ac.uk/pdf/appendixf/OPENspacewebsite_APPENDIX_F_resource_1.pdf.

81 There is some evidence to suggest that while natural gas extraction may be less impactful per unit energy produced on an annual basis compared to wind energy, it may have a significantly larger cumulative ecological footprint over time. See: Jones NF, Pejchar L, 2013. Comparing the ecological impacts of wind and oil & gas development: a landscape scale assessment. PLoS ONE 8 (11), e81391.

82 Jacquet J, 2014. Review of risks to communities from shale energy development. Environ.Sci. Technol. 48 (15): 8321–8333.

been well documented by various studies that have examined the social and health effects of energy extraction in small "boomtowns" in various localities across the world.[83-86]

The effect of an influx of temporary workers (often predominantly composed of young men) has been shown to negatively affect community cohesion, increase the cost of living, and be associated with higher levels of alcohol and drug use, mental illness and violence. Such negative effects typically fall disproportionately on community members least able to bear them. Unless steps are taken to avoid such effects, the increased pressure on local public services can precipitate further negative knock-on effects. Additionally, it is worth noting that beneficial employment generation associated with shale gas in the US has usually been over-stated[87 88 89]and that initial economic booms often transform into long-term social and economic declines.[90 91]

These experiences understandably worry communities in the vicinity of proposed fracking sites, leading to serious stress before the process has even been approved for development. It has been shown that stress and community divisions (and the consequent negative mental health effects) are amplified by a lack of trust and transparency concerning industry and government action.[92]

Another potential effect of fracking concerns the use of considerable quantities of water which could pose localised risks to water supplies.[93] It is presently believed that fracking in the UK would source water directly from the mains water supply.[94] Although the volume of water used per well (10,000 to 25,000L) may appear large when viewed in isolation,[95] when set in the context of overall water supply and use, it is comparable to other industries.[96] However, the impact on water supplies will depend on the total number of active wells at any given time. If large, there is potential for the pressure of water supply to drop periodically and for local water stress to occur.

83 Jacquet J, 2009. Energy boomtowns and natural gas: Implications for Marcellus Shale local governments and rural communities. The Northeast Regional Center for Rural Development: University Park, PA,. Available from: http://aese.psu.edu/nercrd/publications/rdp/rdp43/view.

84 Adgate J, Goldstein B, McKenzie L, 2014. Potential Public Health Hazards, Exposures and Health Effects. Environ. Sci. Technol. 48 (15: 8307-8320. Doi: 10;1021/es404621d.

85 House of Representatives Standing Committee on Regional Australia. 2013. Cancer of the bush or salvation for our cities? Fly-in, fly-out and drive-in, drive-out workforce practices in regional Australia. Canberra: Commonwealth of Australia. http://www.aph.gov.au/parliamentary_business/committees/house_of_representatives_committees?url=ra/fifodido/report.htm

86 Hossain D, Gorman D, Chapelle B, et al. Impact of the mining industry on the mental health of landholders and rural communities in southwest Queensland. Australas Psychiatry 2013; 21: 32-37.

87 Weber J, 2012. The effects of a natural gas boom on employment and income in Colorado, Texas, and Wyoming. Energy Econ. 34 (5, 1580–1588 (Sep. Doi: 10.1016/j.eneco.2011.11.013.

88 Patridge M, Weinstein A, 2013. Economic implications of unconventional fossil fuel production. National Agricultural & Rural Development Policy Center. Available from: http://www.nardep.info/uploads/Brief15_EconomicsFossilFuel.pdf.

89 Mauro F, Wood M, Mattingly M, Price M, Herzenberg S and Ward S, 2013. Exaggerating the Employment Impacts of Shale Drilling: How and Why. Multi-State Shale Research Collaborative. Available from pennbpc.org/sites/pennbpc.org/files/MSSRC-Employment-Impact-11-21-2013.pdf

90 Jacquet J, 2009. Energy Boomtowns & Natural Gas: Implications for Marcellus Shale Local Governments & Rural Communities. NERCRD Rural Development Paper N° 43. Available from: http://aese.psu.edu/nercrd/publications/rdp/rdp43.

91 Christopherson S, Rightor N, 2011. How should we think about the economic consequences of shale gas drilling? A Comprehensive Economic Impact Analysis of Natural Gas Extraction in the Marcellus Shale. Working Paper, City and Regional Planning, Cornell University. Available from: http://cce.cornell.edu/EnergyClimateChange/NaturalGasDev/Documents/PDFs/Comprehensive%20Economic%20Analysis%20project.pdf.

92 Ferrar K, Kriesky, Christen C, Marshall L et al, 2013. Assessment and longitudinal analysis of health impacts and stressors perceived to result from unconventional shale gas development in the Marcellus Shale region. Int. J. Occup. Environ. Health 2013. 19 (2):104–12. Doi: 10.1179/2049396713y.0000000024.

93 Chartered Institute of Environmental Health (CIEH and Scientists for Global Responsibility (SGR 21/7/2014 'Shale Gas and fracking - examining the evidence'

94 EAC heard from the Environment Agency that they expect commercial operators to source their water from water companies.

95 Institution of Civil Engineers (ICE, 8th Jan. 2015. Written Submission to Environmental Audit Committee: Environmental Risks of Fracking Enquiry (FRA070), para 2.1.

96 Chartered Institution of Water and Environmental Management, 2015. Written Submission to Environmental Audit Committee: Environmental Risks of Fracking Enquiry (FRA006, para 4

Summary

While the precise level of risk to human health is indeterminate, the health hazards involved are substantial. The level of risk and threat to health associated with fracking is dependent on multiple factors. A full and proper health impact assessment (HIA) must take into account all of the different potential effects and pathways and assess the additive and compound effect of multiple risks. It must also be tailored to the specific geological, economic, environmental and social characteristics of the surrounding areas.

The uncertainty caused by the multiplicity of factors involved also causes a high level of unpredictability. For example, a study from Northeastern Colorado found that air pollutant emissions associated with shale gas development actually increased after tighter emission standards had been implemented, contrary to what would have been expected, and indicating that regulation cannot be guaranteed to reduce risks.[97]

Of particular importance is the need to assess impact on the basis of fracking activity that is intended to take place at an industrial level. HIAs of one or two wells are inadequate and likely to be misleading. The findings of any HIA should also be disaggregated so that impacts on the groups most affected and most vulnerable can be clearly distinguished within the average risk to the whole population.

A recent study from the US (described as the largest to date) which found a positive association (after adjusting for age, sex, presence of smokers and animals in the household, education level, work type, and awareness of environmental risks) between reported symptoms of illness and proximity of households to natural gas well activities noted three possible causal pathways: contamination of water; exposure to air pollutants; and stress or anxiety related to the proximity of shale gas activity.[98]

Two other factors need to be taken into account when considering the potential risks associated with fracking. One is the professional culture and level of social responsibility of the operators concerned, and the extent to which companies will be under commercial pressure to minimise costs and compromise on safety and ethics. The second is the extent to which the regulatory system here is adequately robust and complete. This report does not comment on the former; but looks at the latter in chapter 5.

3.2 Greenhouse gas emissions, climate change and wider energy policy

One of the impacts of the extraction and use of shale gas is the production of greenhouse gases (GHGs): methane (a potent greenhouse gas[99]) is emitted during the extraction process and CO_2 is emitted on combustion. However, shale gas has been proposed as a transition fuel, to enable economies to phase out carbon intensive fuels such as coal while moving towards clean energy and a decarbonised economy. This proposition assumes that shale gas is a relatively clean energy source that will permanently displace the use of more carbon intensive energy sources (in particular coal and imported liquefied natural gas) that would otherwise have been used. It also assumes that shale gas can be deployed within a timescale compatible with current climate objectives.

This section discusses the validity of these assumptions. Before doing so, it outlines existing climate objectives and the current status of global GHG emission trajectories.

97 Thompson C, Hueber J, Helmig D, 2014. Influence of oil and gas emissions on ambient atmospheric non-methane hydrocarbons in residential areas of Northeastern Colorado. Elementa. 2, 000035.

98 Rabinowitz PM, Slizovskiy IB, Lamers V, Trufan SJ, Holford TR, et al. 2015. Proximity to natural gas wells and reported health status: results of a household survey in Washington County, Pennsylvania. Environ Health Perspect 123:21–26; http://dx.doi.org/10.1289/ehp.1307732)

99 Methane is a much stronger GHG than CO2 (86 times as strong over a 20 year time frame and 34 times as strong over a 100 year time frame). See: http://www.ipcc.ch/report/ar5/wg1/#.Uk21dxbhLdk.

Greenhouse gas emissions and global warming

The level of global warming (measured as an increase in global mean surface temperature) is directly related to the cumulative amount of GHGs emitted into the atmosphere.[100 101] GHGs cause global warming by increasing the amount of energy retained within the earth-atmosphere system.[102] This leads to climate change, altering the frequency of adverse weather events and causing sea level rise; while increased concentrations of atmospheric CO_2 will cause ocean acidification. These changes have significant implications for the human environment as well as the ability of ecosystems to provide the resources and services we rely upon for our existence, including food production, clean water and biodiversity. The threats posed by GHG emissions to society and global health are serious and potentially catastrophic for many areas of the world.[103]

Policy makers have defined a warming of more than 2°C as 'dangerous'[104] and international negotiations are currently focused on reducing cumulative GHG emissions to avoid this level of warming. It has been estimated that a greater than 66% chance of avoiding a 2°C temperature rise[105] would require the cumulative amount of GHGs released between 2011 and 2100 to be no more than the equivalent of 1000 $GtCO_2$. Although the aspiration of a 'greater than 66% chance' of limiting warming to 2°C is not guaranteed to avoid a 2°C rise, it still means a radical reduction in global GHG emissions, reaching either net zero or even negative emissions during the latter half of this century, depending on how quickly GHG emissions can be reduced over the next few decades.[106]

Fossil fuel reserves

There is far more CO2 stored in already-existing fossil fuel resources and reserves than can be emitted if we are to remain within a 1000 GtCO2 budget. In other words, vast amounts of fossil fuels are 'unburnable' and should be left in the ground.

The geographic distribution of 'unburnable fuels' is uneven for various reasons, including differences in the economic, technological and environmental costs of fuel extraction and transportation. A recent analysis which took such factors into account found that to comply with *at least* a 50% chance of keeping warming below 2°C throughout the 21st century, a third of oil reserves, half of gas reserves and over 80% of coal reserves need to remain unburnt, even after accommodating future possibilities for carbon capture and storage (CCS) technology.[107] The same analysis also suggested that about 78% of Europe's shale gas reserves are 'unburnable', but only with the proviso that unconventional fuels *permanently* displace the use of an equivalent amount of coal.

100 Meinhausen M, Meinhausen N, Hare W, Raper S, et al, 2009. Greenhouse-gas emission targets for limiting global warming to 2°C. Nature. 458: 1158-1162. Doi: 10.1038/nature08017.

101 IPCC, 2013. Summary for Policymakers. 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, Qin D., Plattner G., Tignor M. et al (eds.). Cambridge University Press, Cambridge, UK and New York. USA.

102 McCoy D and Hoskins B, 2014. *The science of anthropogenic climate change: what every doctor should know BMJ 2014; 349 doi: http://dx.doi.org/10.1136/bmj.g5178*

103 http://www.medact.org/wp-content/uploads/2014/04/medact_climatescience_Briefing2_Web.pdf

104 United Nations Framework Convention on Climate Change, Conference of the Parties 16, UNFCCC, Cancun, Mexico, 2010.

105 IPCC, 2014. Climate Change 2014 Synthesis Report Table 2.2. Pachauri R. and Meyer L (eds.). Cambridge University Press, Cambridge, UK and New York, USA.

106 IPCC, 2014. Climate Change 2014. Synthesis Report Figure SPM.5. Pachauri R and Meyer L (eds). Cambridge University Press, Cambridge, UK and New York USA.

107 McGlade C and Ekins P, 2015. The geographical distribution of fossil fuels unused when limiting global warming to 2oC. Nature. 517:187-190. Doi:10.1038/nature14016.

In countries where energy systems are heavily reliant on coal, shale gas *may* act as a transition fuel. However, where coal has been or is being phased out, shale gas may not act as a cleaner transition fuel. Furthermore, for shale gas to be a transition fuel it must permanently displace the use of more carbon-intensive fuels worldwide. Otherwise, as noted by the previous Chief Scientific Advisor of the Department for Energy and Climate Change (DECC), Prof David Mackay: "*If a country brings any additional fossil fuel reserve into production, then in the absence of strong climate policies, we believe it is likely that this production would increase cumulative emissions in the long run.*"[108]

A good example of this dynamic in action is provided by the rise in European coal consumption between 2009 and 2012. This stemmed from the rapid increases in North American natural gas production[109] (especially from shale) which resulted in a reduction in US gas prices and the displacement of coal produced in the US. Because European gas prices were largely unaffected by the reductions in US gas prices and, with the coal displaced from the US entering international markets, coal consumption in Europe ended up increasing. Recent US government data show that during the growth in shale gas and oil production, overall CO_2 emissions from all the fossil fuels *produced* in the US rose by approximately 10%, whilst emissions from domestic fuel *consumption* in the US decreased by the same amount.

Clearly, shale gas extraction and use in the UK or elsewhere cannot be conducted in an unrestricted manner, nor in isolation from other fossil fuel use. If new resources are to be developed in the UK, then fewer fossil fuel reserves need to be developed elsewhere if international commitments to limit global warming are to be met.

UK commitments to GHG emission reductions

UK commitments enshrined in the UK Climate Change Act 2008 require it to deliver emission reductions of at least 80% by 2050 and for the rate of reduction to be informed by carbon budgets set for five year periods as advised by the Committee on Climate Change (CCC). Assessments by the CCC to establish the feasibility and costs associated with emission reductions have demonstrated particular difficulties in reducing emissions from some sources such as agriculture, aviation and shipping; thus pointing to other sources, in particular electricity generation and heating in domestic and commercial buildings, needing to deliver more than an 80% reduction in GHG emissions by 2050.[110]

This is highly relevant to the debate on fracking because UK shale gas production is mainly targeted for electricity generation and heating. It is therefore important to examine whether shale gas is a *low* carbon energy source that would *permanently* displace the use of more carbon intensive energy sources *and* be deployable within a timescale compatible with current climate objectives.

108 MacKay D and Stone T, 2013, Potential Greenhouse Gas Emissions Associated with Shale Gas Extraction and Use, Department for Energy and Climate Change, London, UK. Available from: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/237330/MacKay_Stone_shale_study_report_09092013.pdf.

109 Broderick J and Anderson K, 2012. Has US Shale Gas Reduced CO2 emissions? Research Briefing. Tyndall Manchester, University of Manchester. Available from:
tyndall.ac.uk/sites/default/files/broderick_and_anderson_2012_impact_of_shale_gas_on_us_energy_and_emissions.pdf. URL no longer available

110 Committee on Climate Change, 2008. Building a low carbon economy – the UK's contribution to tackling climate change. The Stationery Office, Norwich, UK. Available from: http://image.guardian.co.uk/sys-files/Environment/documents/2008/12/01/BuildingALowCarbonEconomy.pdf.

Shale gas as a low carbon fuel

Life cycle analysis (LCA) techniques are used to quantify the environmental impacts of different fuels throughout their lifetime from extraction to use. This enables a comparison to be made between different energy vectors and a quantification of potential CO_2 savings from switching between fuels such as using shale gas instead of conventional gas, liquefied natural gas (LNG)[111] or coal.

Conducting an LCA is complex and requires detailed data about the source of the fuel (including geological data related to the well or mine), the extraction and processing methods used, and the energy required to store and transport fuel. It is difficult to elicit generalisable results from particular sites or for particular fuels. Nonetheless, it enables a comparison of the emissions intensity of different fuels and an understanding of the main influencing factors.

The carbon footprint of shale gas is dependent on various specific characteristics: where there are high levels of liquid unloading and poor fugitive emission controls, then shale gas GHG emission levels could be high and approach those of the least-polluting coal-fired units.[112] However, this combination of poor performance is unlikely to be representative of all shale gas generation and regulations mandating emission controls should avoid this worst case scenario in the UK.

One recent review of studies indicates that shale gas is clearly superior to coal when used for electricity generation (Table 1).[113] It has been suggested that for shale-gas electricity generation to be a superior alternative to coal-fired generation, the leakage rate of fugitive methane emissions needs to be less than 3.2%.[114] While it may be reasonable to assume that this would be the case with fracking in the UK; some experts caution that "the literature on this issue is not yet at a mature enough stage to have any confidence on what a reasonable range for fugitive emissions might be".[115]

Table 1: Comparison of the life cycle emissions from electricity produced by different fossil fuels

Fuel source	Median estimate (gCO_{2e}/kWh)	Range (gCO_{2e}/kWh)
Shale gas	470[a]	434-746[a]
Conventional –gas	450[a]	438-647[a]
Coal	980[b]	820-1,370[b]

a: Harmonized estimates of the life cycle greenhouse gas emissions by Heath et al 2014.
b: Harmonized estimates of the life cycle greenhouse gas emissions of modern coal-fired generation facilities by Whitaker et al – cited by Heath.

The same review also revealed that shale gas generates slightly more emissions than conventionally sourced gas. A study commissioned by the UK CCC comparing UK shale gas to imported LNG and conventional gas similarly concluded that the life cycle emissions of shale gas may be no worse than conventional gas, but could be better than LNG depending in particular on the amount of fugitive methane emissions.[116]

111 Liquefied natural gas is generally the same as 'conventional gas' except that it is liquefied for the purpose of storage and transportation. This requires energy. Hence, the LCA for LNG differs from that of conventional gas.

112 Howarth R, Santoro R, Ingraffea A, 2012. Venting and leaking of methane from shale gas development: response to Cathles et al. Clim. Chang. 113 (2): 537–549. Doi: 10.1007/s10584-012-0401-0.

113 Heath G, O'Donoughue P, Arent D, Bazilian M, 2014. Harmonization of intial estimates of shale gas life cycle greenhouse gas emissions for electric power generation. PNAS. 111 (31): E3167 – E3176. Doi:10.1073/pnas.1309334111.3

114 Alvarez R, Pacala S, Winebrake J, Chameides W, Hamburg S,2012. Greater focus needed on methane leakage from natural gas infrastructure. PNAS. 109 (17): 6435-6440. Doi: 10.1073/pnas.1202407109.

115 McGlade C, Ekins P, Bradshaw M and Watson J, 2015. Conditions for environmentally-sound UK shale gas development http://www.wbs.ac.uk/wbs2012/assets/PDF/downloads/press/ShaleGasUKERC1502Fin.pdf

116 Committee on Climate Change (2013) Reducing the UK's Carbon Footprint. Committee on Climate Change, London, UK 12 April 2013. http://www.theccc.org.uk/wp-content/uploads/2013/04/Reducing-carbon-footprint-report.pdf

There have been numerous research efforts to both quantify and identify mitigation options for methane leakage from natural gas operations.[117-125] Data on the size of these emissions are still limited, with measurements of leakage rates in the US ranging from 0.67% to 6.2% for unconventional gas sites, depending on site-specific factors.[126] In the UK context, while life cycle GHG emissions from electricity generated by shale gas is highly likely to be lower than coal-fired generation, its potential benefit as a substitute for existing gas sources is uncertain.

If methane leakage rates are less than 2%, shale gas could provide benefits over the use of imported LNG, but may perform worse than conventional gas sourced within the UK or imported via pipeline from Norway.[127] This corresponds with the findings of an analysis which finds shale gas to be comparable to conventional gas in terms of its global warming impact, but only under the conditions of tight regulation.[128]

Shale gas as a transition fuel

In the UK, emission savings would be achieved if shale gas were used as a replacement for coal in the UK. However, the potential for shale gas to act as a transition fuel towards a low-carbon energy system is time-limited.[129] This is partly because existing coal fired power plants are already scheduled for closure due to a combination of legislation to control air pollution and the cost of carbon emissions under the EU Emissions Trading Scheme. In addition, party leaders have pledged to prevent new coal-fired plant from being built without CCS technology.

As a result, rather than displacing more carbon intensive fuels, shale gas is more likely to displace imported gas and thus have a small effect in reducing GHG emissions.[130] Of greater concern is that shale gas could end up competing with cleaner, lower carbon energy sources, lock the UK into longer period of reliance on fossil fuels, and delay investment in renewable energy development and

117 Pétron G, Frost G, Miller B., Hirsch A et al, 2012. Hydrocarbon emissions characterization in the Colorado Front Range: a pilot study. J. Geophys. Res. 117 (D4): D04304. Doi: 10.1029/2011JD016360.

118 Pétron G, Karion A, Sweeney C, Miller B, 2014. A new look at methane and non-methane hydrocarbon emissions from oil and natural gas operations in the Colorado Denver–Julesburg Basin. J. Geophys. Res. Atmos. 119 (11):6836-6852. Doi: 10.1002/2013JD021272.

119 Allen D, Torres V, Thomas J, Sullivan D et al, 2013. Measurements of methane emissions at natural gas production sites in the United States. PNAS. 110 (44): 17768 - 17773. Doi: 10.1073:pnas.1304880110.

120 Allen D, Pacsi A, Sullivan D, Zavala-Araiza D, et al, 2015a. Methane emissions from process equipment at natural gas production sites in the United States: pneumatic controllers. Environ. Sci. Technol. 49 (1): 633–640. Doi: 10.1021/es5040156.

121 Karion A, Sweeney C, Pétron G, Frost G et al, 2013. Methane emissions estimate from airborne measurements over a western United States natural gas field. Geophys. Res. Lett. 40 (16): 4393–4397. Doi: 10.1002/grl.50811.

122 Brandt A, Heath G, Kort E, O'Sullivan F et al, 2014. Methane leaks from North American natural gas systems. Science. 343 (6172): 733–735. Doi: 10.1126/science.1247045.

123 Peischl J, Ryerson T, Brioude J, Aikin K, et al, 2013. Quantifying sources of methane using light alkanes in the Los Angeles basin, California. J. Geophys. Res. 118 (10): 4974–4990. Doi:10.1002/jgrd.50413.

124 Caulton D, Shepson P, Santoro R, Sparks J et al., 2014. Toward a better understanding and quantification of methane emissions from shale gas development. PNAS. 111(17): 6237-6242. Doi/ 10.1073/pnas1316546111.

125 Schneising O, Burrows J, Dickerson R, Buchwitz M et al, 2014. Remote sensing of fugitive methane emissions from oil and gas production in North American tight geologic formations. Earth's Future. 2 (10): 548-558. Doi: 10.1002/2014EF000265.

126 Heath G, O'Donoughue P, Arent D, Bazilian M, 2014. Harmonization of intial estimates of shale gas life cycle greenhouse gas emissions for electric power generation. PNAS. 111 (31): E3167 – E3176. Doi:10.1073/pnas.1309334111.3

127 Committee on Climate Change (2013) Reducing the UK's Carbon Footprint. Committee on Climate Change, London, UK 12 April 2013. http://www.theccc.org.uk/wp-content/uploads/2013/04/Reducing-carbon-footprint-report.pdf

128 Stamford S and Azapagic A, 2014. Life cycle environmental impacts of UK shale gas. Applied Energy 134: 506–518

129 McGlade C, Bradshaw M, Anandarajah G, Watson J, Ekins P, 2014. A Bridge to a Low-Carbon Future? Modelling the Long-Term Global Potential of Natural Gas. UK Energy Research Centre, London, United Kingdom. Available from: http://www.ukerc.ac.uk/news/gas-can-be-a-bridge-to-a-low-carbon-future.html

130 MacKay D, Stone T, 2013. Potential Greenhouse Gas Emissions Associated with Shale Gas Extraction and Use. Department for Energy and Climate Change. London, UK. Available from: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/237330/MacKay_Stone_shale_study_report_09092013.pdf

production.[131] [132] This has been confirmed by other studies which have demonstrated the potential for gas to displace low and zero-carbon sources of energy as much as displacing coal. An important assessment of the impact of market-driven increases in global supplies of unconventional natural gas, published in Nature and based on simulations from five state-of-the-art integrated assessment models of energy–economy–climate systems, found little evidence of change in overall GHG emissions.[133]

The CCC recommended that in order to meet its climate commitments, the emissions intensity for electricity generation needs to fall on average to < 70g/kWh by 2030.[134] According to the CCC, such a target is consistent with a high use of renewable and nuclear energy, both of which have life cycle emissions that are significantly lower than shale gas (even if combined with CCS technology).[135] Within this intensity target, the role of gas fired plants are limited to providing short-term back-up electricity generation. To meet UK 2050 emissions reduction commitments, the use of gas for electricity generation needs to fall dramatically by 2030 while domestic and commercial sector gas use is phased out almost completely by 2050.[136] By contrast, a greater use of gas in the UK energy system implied by Government pronouncements on the development of the UK's shale gas industry would endanger, if not preclude, the ability of the UK to contribute to limiting global warming to 2°C.

The deployment of UK shale gas would not come within a timescale compatible with current UK and international climate objectives. For example, assuming a shale gas industry is in operation and producing gas by 2025, the 10% recovery of Bowland shale "gas-in-place" that was estimated by BGS[137] substantially exceeds the total available cumulative carbon budget recommended by the CCC (from 2025), even allowing for a best case deployment of CCS technology and an emphasis on gas rather than coal and biomass.

Any large-scale and long-lived UK shale gas industry would therefore need to include a substantial export element which would then need to include the carbon footprint of transportation within its life cycle emissions.[138] Furthermore, without internationally binding emission limits, this would likely contribute to an increase in global emissions.

Impacts of UK shale gas on gas prices

It is now generally accepted that shale gas will not lead to a reduction in gas prices, in contrast to previous claims that it would.[139] These claims were, in part, a reflection of experience in the US where fracking led to large reductions in gas prices. There are two key reasons why shale gas production is unlikely to reduce energy bills: the likely cost of extraction in the UK, and the nature of the UK and European gas market.

131 Letter from Lord Deben to Rt Hon Ed Davy MP on behalf of the CCC "The need for a carbon intensity target in the power sector. 13 Sept 2013. http://www.theccc.org.uk/publication/letter-the-need-for-a-carbon-intensity-target-in-the-power-sector/

132 Stevens P, 2014. Why Shale gas won't conquer Britain. New York Times. 14 Jan 2014. Available from: http://mobile.nytimes.com/2014/01/15/opinion/why-shale-gas-wont-conquer-britain.html?_r=0

133 McJeon H, Edmonds J, Bauer N, Clarke L, 2014. Limited impact on decadal-scale climate change from increased use of natural gas. Nature 514: 482–485. Doi: 10.1038/nature13837.

134 Committee on Climate Change (2008) Building a low-carbon economy- the UK's contribution to tackling climate change. The Stationery Officer, Norwich UK.

135 Committee on Climate Change (2013) Reducing the UK's Carbon Footprint. Available at: http://www.theccc.org.uk/wp-content/uploads/2013/04/Reducing-carbon-footprint-report.pdf

136 Committee on Climate Change (2008) Building a low-carbon economy- the UK's contribution to tackling climate change. The Stationery Officer, Norwich UK.

137 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.

138 Alternatively, it would imply a smaller scale level of industrial development which call into question the economic viability of shale gas extraction.

139 For example, the Prime Minister once wrote that that "fracking has real potential to drive energy bills down" while the Chancellor of the Exchequer stated shale gas was "a major new energy source that can reduce energy bills for families, for businesses".

According to the International Energy Agency (IEA), operating costs for drilling companies in Europe will be 30-50% higher than in the US[140] due to less-promising geology, higher population density and the lack of a competitive onshore drilling and services industry. Although costs may be driven down as the industry develops, commentators have expressed doubt as to whether the scale of development needed to bring costs down would ever be socially acceptable.[141] In addition, such large-scale development would require long-term shale gas production which would likely be incompatible with the UK's carbon budget.

The integrated European gas market is also very different to the more self-contained market of the US where the increased supply of shale gas forced down energy prices considerably.[142] In the more integrated European gas market, the effect of UK shale gas production on prices is likely to be small unless it constitutes a large proportion of the overall quantity of gas in the market.[143] The House of Lords Economic Affairs Committee similarly concluded that "the UK gas market's substantial imports and its links to continental European markets also limit the scope for home-produced shale gas to bring about price cuts on US lines".[144]

140 International Energy Agency, 2012. World Energy Outlook 2012.Golden Rules for a Golden Age of Gas.Paris, France. Pg 54. Available from: iea.org/publications/freepublications/publication/WEO2012_GoldenRulesReport.pdf - URL no longer available

141 Tom Burke and Professor Paul Stevens Evidence to the Environmental Audit Committee's inquiry into shale gas http://data.parliament.uk/writtenevidence/committeeevidence.svc/evidencedocument/environmental-audit-committee/environmental-risks-of-fracking/oral/17532.html

142 Diccolo J, Fowler T, 2012, Exxon: Loosing our Shirts on Natural Gas. Wall Street Journal, 27th June 2012. Available from: http://www.wsj.com/articles/SB10001424052702303561504577492501026260464

143 MacKay D, Stone T, 2013. Potential Greenhouse Gas Emissions Associated with Shale Gas Extraction. Op. cit.

144 House of Lords Economic Affairs Committee, 2014. The Economic Impact on UK Energy Policy of Shale Gas and Oil. Available from: http://www.publications.parliament.uk/pa/ld201314/ldselect/ldeconaf/172/17202.htm.

Chapter 4: The specific features of fracking in the UK

Much of the available understanding of shale gas production is derived from the United States (US). While this is useful, differences in the UK must be taken into account.

For example, geological differences with the shale formations in the UK mean, among other things, that fracking in the UK may involve a greater number of lateral sections per vertical section. This means a higher level of intensity of fracking, with a single wellpad (an area of land of usually between 1 to 3 hectares), possibly being the location for up to 60 boreholes (vertical and horizontal). In Lancashire, where shale beds cover an area of about 400km^2, this could potentially translate into a hundred wellpads with a total of up to 6,000 boreholes.

Shale formations in the Lancashire region, where shale gas is believed to be most commercially viable, are deeper than in the US.[145] [146] While this depth may reduce the risk of pollutants rising to the surface and contaminating aquifers, because the shale is more geologically faulted, a risk of contamination of aquifers remains. It is reported that 47% of principal aquifers are underlain by shales/clays that are potentially prospective for gas or oil.[147] According to the BGS, further work is required to adequately assess the full extent to which this leaves groundwater vulnerable to contamination and pollution. In its submission of evidence to the Environmental Audit Committee (EAC), BGS stated: "The difficulty lies in the fact that below c.200m there is very little information and data on the hydrogeological properties and potential for movement of pollutants through rocks below this depth".[148]

Some of the shale formation in the UK may also have a greater predisposition towards seismic activity, which could damage wells and lead to fault lines that predispose to environmental pollution. The EAC noted this concern and stated that more effort is required to understand and map specific local geological conditions, including the influence of historic mining activity.

A non-geological difference is that in the UK, most drinking water originating from surface sources (reservoirs, lakes and rivers) or groundwater (aquifers) has undergone treatment and quality control. This is unlike in the US where there are more communities living in the proximity of fracking sites who are reliant on untreated water drawn directly from private water wells.

A more important consideration for the UK in comparison to the US is the closer proximity and greater size of populations in and around potential fracking sites. Fracking sites in the UK may also generally be closer to agricultural and tourism activity compared to the US.[149]

145 Smythe DK, 2015.Hydraulic fracturing in a thick shale basin: seismic reflection methods do not reliably predict faults in the Bowland Basin, Lancashire, UK. *Geophysical Research Letters* (submitted)

146 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

147 British Geological Survey, 2015. Written Submission, Environmental Audit Committee: Environmental Risks of Fracking Enquiry (FRA077).

148 British Geological Survey, 2015. Written Submission, Environmental Audit Committee: Environmental Risks of Fracking Enquiry (FRA077).

149 While much fracking in the US has taken place in population sparse areas within the US, fracking in the US has also been conducted in more population dense areas as well, and there are also fracking wells situated within farms as well.

Finally, there will be operational differences. For example, in the UK, water for fracking is expected to be largely mains water and piped in,[150] whereas in many US sites, water has had to be trucked in. Importantly, regulatory differences between the UK and the US may lead to some differences in the practice of fracking. For example, it has been stated that the use of hazardous chemical additives in fracking fluid will be prohibited in the UK.[151]

150 It is possible that in the future water may need to be abstracted directly from local sources of surface or groundwater. It should also be noted that the volume of water required will depend on the amount of flowback that is recycled and re-used for fracking.

151 In the US, one assessment of the hundreds of chemicals associated with fracking found that 75% had potential dermal, ocular, respiratory and gastrointestinal effects; 40–50% had potential nervous or immune system effects; 37% had potential endocrine system effects; and 25% were potential carcinogens or mutagens. See: Colborn T, Kwiatkowski C, et al (2011). Natural gas operations from a public health perspective. Human and Ecological Risk Assessment: An International Journal 17(5): 1039–56

Chapter 5: Mitigating Risk Through Regulation

Claims that the regulatory system is capable of preventing harm and mitigating risk need to be carefully considered. The UK has a reputation for sound health and environmental regulation. There are some differences in the regulatory system across the different devolved administrations of the UK. What follows is a discussion specific to the system in England.

The regulatory system for fracking

Responsibility for overall coordination of policy on unconventional oil and gas lies with the Department of Energy and Climate Change (DECC), within which the Office of Unconventional Gas and Oil (OUGO) is responsible for encouraging and overseeing unconventional oil and gas exploration and production. The Department for Environment, Food and Rural Affairs (DEFRA) has lead responsibility for the environmental aspects of shale gas policy, while the Department for Communities and Local Government (DCLG) is responsible for the local planning system. Overall responsibility for climate change and seismicity also lies with DECC.

Petroleum Exploration Development Licences are granted to operators by DECC, giving them exclusive rights to drill for and get minerals in an area.[152] Once operators have negotiated access from the relevant landowner, they must obtain planning permission.

In England, planning permission is obtained from the local government Minerals Planning Authority (MPA). Separate planning permissions, including from local government development control, are sometimes required for different stages of the process (exploration, appraisal and production), but not always. The operator must additionally consult the Environment Agency (EA), an executive non-departmental public body sponsored by DEFRA, which is responsible for issuing the required environmental permits related to, among other things, water abstraction; wastewater discharge; management and disposal of mining wastes; flaring; and management of radioactive waste. It is also responsible for assessing hazards associated with fracking fluid and is expected to work through the Joint Agencies Groundwater Directive Advisory Group.[153]

The local government planning system should take account of the effects of pollution and industrial activity on the local area, and determine if a formal Environmental Impact Assessment (EIA) is required. If so, the operator is obliged to put together an assessment of the potential risks to people, plants, animals, soil, water, climate, landscape, and architectural and archaeological heritage, and the proposed steps to mitigate such risks. Planning authorities are also empowered to enforce various conditions attached to the planning permission, although they have limited resources with which to carry out enforcement.

A further element of the regulatory system is the Health and Safety Executive (HSE) which reports to the Department for Work and Pensions. HSE is responsible for ensuring safe working practices at and around the wellpad, including safe and proper well construction and must be notified at least 21 days prior to any drilling conducted by an operator so that it can assess the well design and ensure that measures are in place to control major hazards. It is also expected to continue monitoring operations by reviewing weekly reports submitted by the well operator.

152 This does not necessarily involve fracking as the licences also cover conventional exploration and production of hydrocarbons.

153 JAGDAG is comprised of DEFRA, the Welsh Government, the Environmental Protection Agency of Ireland, PHE and industry representatives.

Concerns about the adequacy and capacity of the regulatory system

Several aspects of the regulatory system for fracking are of concern.

To begin with, many of the existing regulations were designed primarily for off-shore and *conventional* onshore gas and do not adequately accommodate the challenges and specific risks posed by on-shore shale gas operations.[154] As such the system does not fully cover, among other things, the proximity of local communities to fracking operations and their impact on other economic activities such as tourism and agriculture.[155]

Although a 'regulatory roadmap' for onshore oil and gas *exploration* has been published by DECC and provides some detail about best practice related to the licensing, permitting and permissions process for onshore oil and gas exploration, including shale gas, this is not legally binding and does not cover shale gas *production*.[156] Technical guidance to clarify which environmental regulations apply to the onshore oil and gas exploration and what operators need to do to comply with those regulations, published by the EA in draft form, is similarly a weak form of regulation.[157]

There are other regulatory gaps and uncertainties. For example, the guidance published by the EA lacks detailed specifications about the mandatory requirements for 'reduced emission completions' (a term used to describe practices to prevent fugitive methane emissions during well completions and workovers following fracking).[158] Regulatory processes for the public disclosure of data about fracking fluid and flowback, and their independent verification, are also absent. Detail about the quality, frequency, amount and comprehensiveness of pollutant monitoring is also unclear. We also do not know how flowback will be treated and disposed of; or whether it will be recycled and re-used. Another concern is the proposal that plugged and abandoned wells will be monitored for only one year after abandonment, and that this is to be conducted by the operators themselves.

This relates to another set of concerns about the regulatory system being over-dependent on self-regulation and on a voluntary 'goal-setting approach' in which operators are assumed to apply best available techniques and good industry practices. The role of independent monitoring or independent verification of operator reports is limited. This includes the requirement for an 'independent and competent person' to examine the integrity and quality of well design and construction. While described as independent, such a person is often paid for or employed by the operator, and usually conducts the review and examination of well specifications and design as a paper exercise. As such, there is no mandatory and fully independent regulatory oversight of actual construction of wells, and no provision for unannounced and appropriately frequent spot checks, nor for inspections of well integrity to occur across the lifecycle of a well, including after abandonment.

Compounding the over-reliance on self-regulation is a limited sanctions regime in the event of non-compliance with safety standards and best practice. The proposal to require companies to secure a bond to insure them against the cost of any potential liability has not been adopted as policy and means that too much of the risk associated with fracking is left with local communities and public authorities. Stricter safeguards may also be required to prevent fracking operators from passing the ownership and liability of commercially non-viable wells onto subsidiary companies that subsequently go into

154 This includes the specific regulations covering Borehole Site and Operation Regulations (BSOR) and Design and Construction Regulations (DCR).

155 Hill M, 2014. Shale gas regulation in the UK and health implications of fracking, The Lancet Vol 383, No, 9936 p 2211-221

156 DECC, 2013. Regulatory Roadmap: Onshore Oil and gas Exploration in the UK Regulation and Best Practice. Available at https://www.gov.uk/government/publications/regulatory-roadmap-onshore-oil-and-gas-exploration-in-the-uk-regulation-and-best-practice.

157 Environment Agency, 2013b. Draft Technical Guidance for Onshore Oil and Gas Exploratory Operations. https://www.google.co.uk/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0CCIQFjAA&url=https%3A%2F%2Fconsult.environment-agency.gov.uk%2Ffile%2F2582905&ei=vB4PVff2FeOW7AbGooHAAQ&usg=AFQjCNHGvQ4f2PVbU94Stn9qS9XksN7n9Q

158 Other aspects of shale gas operations which lack detailed specifications relate to use of wireline tools, supervisory control and data acquisition (SCADA), instrumentation calibrated to national standards for monitoring, location of instruments (height and distance from well head), sampling interval, tamper proof data logging or publication to web for immediate transparency.

administration shortly after. Although the industry has stated that they will develop an insurance mechanism to cover full liability in the event of a pollution incident, this remains only a claim and would, in any case, offer weaker protection than a legally-mandated bond agreement.

Finally, there are valid concerns about the capacity of the various regulatory bodies, including local government, which have been weakened by staff and budget cuts and which may lack specialist expertise in shale gas production. This concern is accentuated by the reality that the system is challenged by being relatively fragmented and spread across different directives and multiple bodies and by the fact that a new framework for shale gas developments issued in 2013 by the Treasury has set a target for the EA to process permit applications for drilling and 'coring' within two weeks rather than the present average of 3-6 months.[159]

Summary

While the degree to which these concerns represent serious deficiencies is debatable, it is clear that no assurance can be given that the system is adequately robust and protective of human and ecological health.

159 This is significant because it removes public participation from the process – that is local communities most likely to be affected by the activities are not entitled to give their views before work starts.

Chapter 6: What should be concluded?

As recently as 2008, there was only a handful of studies on the health effects of fracking. There are now over 450 peer-reviewed studies, reviews and commentaries. A significant majority of the studies indicate potential risks or actual adverse health outcomes associated with shale gas development. Elevated concentrations of air pollutants and indications of potential or actual incidents of water contamination have been frequently found. Reports of adverse health outcomes related to shale gas development in the US also show symptoms that are common across geographic space and consistent with what one would expect from exposure to some of the known toxic pollutants associated with fracking. A database of these publications together with an accompanying analysis has been published by PSE Health Energy in the US.[160 161]

Fracking is also a disruptive and intrusive activity that will spoil the natural environment; create noise and light pollution; and impose a variety of social and economic stressors onto surrounding communities. A multitude of factors determine the precise level of risk and actual impact on health. These include geological, social, demographic and operator-related factors. While much of the experience of fracking and the evidence of its impact has been generated from the US and other countries, it is notable that the risks associated with fracking could be greater in England because of geological factors, the density and size of surrounding populations, and the proximity of agricultural and tourism activity.

The risks and harms associated with fracking in a small area with one or a few boreholes are not comparable to the risks and harms associated with fracking on an industrial scale. The risks and impact of multiple wellpads with up to sixty boreholes need to be modelled and examined. At present, no attempt has been made to assess the health and environmental impact of fracking at an industrial scale in the UK.

Although a growing body of literature indicates that fracking cannot be made entirely safe through *any* regulatory framework (especially in densely-populated areas), it is possible for risks to minimised and managed. It is important to acknowledge that many industrial activities cause pollution and carry some degree of risk to human and environmental health. A key question is whether the risks associated with fracking can be kept down to a level that is considered acceptable.

At present, the regulatory system for fracking is insufficiently clear, complete or robust. These deficiencies are accentuated by indications that the capacity of regulators are being eroded by budget and staff cuts.

Should a more robust system be developed for fracking, questions would need to be raised about its cost and what effect this would have on the economic viability of shale gas development. Here it is important to make a distinction between economic and commercial viability; and to ensure that any assessment of economic viability includes an accounting of social and environmental costs and benefits.

Various medical and scientific organisations and scholars from different countries have formally highlighted the legitimacy of public health concerns whilst calling for more data and better studies on the health effects of fracking. At the same time, several jurisdictions across the world have concluded,

160 psehealthyenergy.org/site/view/1180 - URL no longer available

161 Hays J and Shonkoff S, 2015. Toward an understanding of the environmental and public health impacts of shale gas development: an analysis of the peer-reviewed scientific literature, 2009-2014. Available at: (psehealthyenergy.org/data/Database_ Analysis_2015.1_.27_1.pdf - URL no longer available)

on the basis of existing evidence, that the risks and harms associated with fracking outweigh the potential benefits.

France and Bulgaria have banned the process outright. New Brunswick, Canada has also enacted a moratorium on all forms of fracking. New York State in the US recently effectively prohibited shale gas development, citing public health risks as the primary reason.[162] According to Howard Zucker, New York State Health Commissioner, '*the potential risks* (to health) *are too great, in fact not even fully known, and relying on the limited data at present available would be negligent.*'[163]

On the basis of our existing knowledge, it would be both prudent and responsible to call for, at the very least, a five year moratorium on all activities related to shale gas development, in order to provide the time to:

a. Learn from more research that will be published in due course
b. Debate and correct the deficiencies and uncertainties that have been identified in the current regulatory system
c. Conduct a comprehensive and holistic health impact assessment that accounts for all the potential risks to health, including their cumulative and compound effects on each other; *and* be tailored to the specific geological, economic, environmental and social characteristics of the areas targeted for fracking; *and* be based on projected levels of fracking at an industrial scale.

On top of this, any consideration about the safety of fracking must incorporate an assessment of its impact on GHG emissions and climate change. Global warming is a real phenomenon, and there is virtually complete scientific, public and political consensus that is driven largely by man-made GHG emissions.

Shale gas is a fossil fuel. It produces CO_2 when combusted. The extraction of shale gas will also release some amount of methane – a more potent GHG than CO_2 - into the atmosphere. It can only be considered a clean source of energy or a useful transition fuel towards a decarbonised energy system under very specific conditions and within a certain timeframe that cannot be met.

Furthermore, its development could result in displacing renewable and low-carbon sources of energy instead of displacing 'dirty coal'. The current abundance of relatively low cost natural gas, coupled with heavy subsidies and a lax regulatory environment for fossil fuels, still creates an economic environment that is inappropriate and non-conducive towards renewable energy development. This needs to change.

On this basis and given the serious and potentially catastrophic threats associated with climate change, the most logical and rational conclusion is to abandon the current policy of encouraging unconventional shale gas extraction in the UK. Instead, we must embark upon a policy of encouraging faster development of clean energy and implementing plans to reduce energy waste.

162 New York State Department of Health, 2014. A Public Health Review of High Volume Hydraulic Fracturing for Shale Gas Development [Internet]. Available from:.
https://www.health.ny.gov/press/reports/docs/high_volume_hydraulic_fracturing.pdf

163 The decision of New York exemplifies the application of the precautionary principle which states: 'When an activity raises threats of harm to human health or the environment, precautionary measures should be taken even if some cause and effect relationships are not established scientifically. In this context the proponent of the activity, rather than the public, should bear the burden of proof' http://www.gdrc.org/u-gov/precaution-3.html; http://www.sehn.org/Volume_3-1.html

Appendix 1: Biographical information

Dr David McCoy is a public health doctor. In the course of his professional life, he has worked in a range of clinical and public health settings as both an academic and practitioner. He is currently a senior academic at the Centre for Primary Care and Public Health in Queen Mary University London and the Director of Medact, a UK-based public health charity. He recently worked as a Director of Public Health in a Primary Care Trust in London and as head of public health intelligence in North West London. He is a Fellow of the Faculty of Public Health and has a doctorate from the London School of Hygiene and Tropical Medicine, University of London. He lives in London.

Dr Patrick Saunders is a Consultant in Public Health, Visiting Professor of Public Health at the University of Staffordshire, Honorary Senior Lecturer at the University of Birmingham, and Associate Director of the World Health Organisation Centre for Chemical Incident Management. He graduated in Environmental Health in 1979 and has held service, research, teaching and management posts with the WHO, Health Protection Agency, local government, the NHS and a number of universities. His research interest is in the public health impact, especially on reproductive health, of exposure to low levels of chemicals.

Dr Frank Rugman is a medical doctor and retired consultant haematologist. He is a visiting Research Fellow at the London School of Hygiene & Tropical Medicine, as physician assessor for the Preventable Incidents, Survival & Mortality study 2010-15 (PRISM 1 & 2); an associate lecturer at the Open University; and a peer-reviewer in anticoagulant treatment for the British Medical Journal. He has published evidence to a Select Committee Report on Pesticides and in 2015 to the Environmental Audit Committee. He lives in an area that may be affected by shale gas extraction

Mike Hill is a chartered electrical engineer and presently a director of a small engineering consultancy. He has worked in oil and gas (wireline, seismic survey and now process automation) for over twenty years. He has written numerous Briefing Notes and papers on fracking, with particular emphasis on regulation, inspections and monitoring. He is cited on the RS/RAE Shale Gas Report of 2012 and is as an expert on the Technical Working Group BREF-MTWR under the Joint Research Council for the EU Commission. Mike lives with his wife and twin sons in Lytham St. Annes, Lancashire, an area which may be affected by shale gas extraction.

Dr Ruth Wood is a lecturer in environment and climate change at the University of Manchester. She has over 10 years research experience in climate change mitigation and energy systems and has contributed to a number of reports examining the greenhouse gas emissions associated with shale gas exploitation in the UK.

Dr Adam Law is President of PSE Healthy Energy and Clinical Assistant Professor of Medicine at Weill Cornell Medical College, USA.

Jake Hays, MA is the Director of the Environmental Health Program at PSE Healthy Energy. He lives in New York City and has worked on the environmental and public health dimensions of shale gas development from Weill Cornell Medical College since 2011

Professor George Morris is an independent consultant in Environmental Public Health. He has worked in local government , in university teaching and research and as an NHS Consultant in Environmental Public Health/Health Protection. He has published widely in the area of environmental health. During a 5 year secondment to Scottish Government he provided scientific advice to policy colleagues and ministers. He led initial development of the innovative 'Good Places Better Health' project which subsequently emerged as the key environmental health policy initiative of Scottish Government.

Dr Angela Raffle is a public health doctor with 30 years experience of working in the NHS, local government and academia. She helped establish the UK National Screening Programmes is lead author of an award winning international textbook on screening. For the last five years she has worked on public health aspects of climate change and resource depletion.

Dr John Middleton is an independent Consultant in Public Health and a former Director of Public Health in Sandwell.

David Kidney is a former UK Member of Parliament and a DECC minister.