Fracking: What's the evidence?

"There is no amount of regulation that can overcome human error."

- Darin Barter, Alberta Energy Resources Conservation Board

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Foreword

This report will outline our current interpretation of the key research and address evidence surrounding the full range of issues that have been raised around the controversial drilling process now known as "fracking." Changing conclusions are inherent to all scientific research, which necessarily has to incorporate new information and analysis. Greenpeace encourages readers to view this publication as a "living document" rather than a report or academic analysis, which will regularly be updated as new findings are made public. Each new version will be updated numerically; this is version 1.0 (November 2013). Readers are encouraged to get in touch if they feel there is evidence missing or if they have a significantly different interpretation of the evidence presented.

Acronyms

Bcf	Billion cubic feet
CCS	Carbon Capture and Storage
CBL	Cement bond log
CCC	Committee on Climate Change
DCLG	Department for Communities and Local Government
DECC	Department of Energy and Climate Change
EA	Environment Agency
HIA	Health impact assessment
IoD	Institute of Directors
IPCC	Intergovernmental Panel on Climate Change
IEA	International Energy Agency
LCA	Life-cycle assessments
LNG	Liquified natural gas
ML	Richter local magnitude
NORM	Naturally Occurring Radioactive Material
NMHC	Non-methane hydrocarbon
PHE	Public Health England
Tcf	Trillion cubic feet
UKCS	United Kingdom Continental Shelf
UNEP	United Nations Environment Programme
VOC	Volatile organic compound

1. Summary: The case against fracking

What is fracking - hasn't it been going on for ages?

Fracking is a way of extracting oil or gas from the ground by injecting water, sand and chemicals at high pressure to split apart the formation and enable the oil or gas to flow up the well. It is normally used alongside horizontal drilling, in which the wells are turned to follow the rock containing the oil or gas.

The process was transformed in the 1990s to extract unconventional reserves of gas and oil, such as shale gas, tight oil or coal bed methane. Fracking these harder to reach reserves is called "high volume" fracking because it uses far more water and chemicals.

Fracking unconventional oil and gas is new to the UK. The government has told residents living near fracking sites that this is the first time "high volume" fracking for gas has taken place.

What does it mean for the climate?

The world already has lots of oil and gas. In fact, at current use, the technically recoverable gas we've already discovered would last for 250 years – according to figures from the International Energy Agency (IEA). That's why the IEA suggests that over the next forty years nearly half the world's proven gas (and oil) supplies need to be left in the ground if we are to avoid dangerous climate change. Nobody knows for sure what it will cost to get gas or oil out of the ground in the UK but US analysts Bloomberg think it will cost far more than fracking in the US. It's very unlikely, therefore, that it is going to put any other fossil fuel producers out of business. It's just more gas for the world to use.

The UK's chief scientist, in a report for the government, warned that unless a global deal to cap emissions is reached, going out and finding more fossil fuels "would increase cumulative emissions in the long run. This increase would work against global efforts on climate change." The UK also has its own carbon budgets as part of the climate change act which all parties support. If the UK were to burn 10% of the available shale gas resource identified by the British Geological Survey in the Bowland-Hodder shale, the CO2 produced would occupy more than 80% of our remaining carbon budget to 2050.[1]

But don't we need the gas?

The UK already imports gas but as we take steps to cut emissions and tackle climate change our gas imports should fall without the need to frack. The government's independent Committee on Climate Change (CCC) advises that to meet the UK's legally binding climate targets our power network should be almost carbon free by 2030. Just two decades later – by 2050 – UK homes should no longer be relying on gas for heating. That means we simply won't need as much gas. A study by the National Grid found that if the UK takes steps to invest in clean energy gas use will fall by over 40% by 2030.

UK gas production from the North Sea will also fall – but by less – which means UK gas imports will decrease from current levels. Indeed if Norway's production estimates are right we can probably meet our needs from the North Sea alone, and that's before you take into account new forms of energy. A study by the National Grid found that biogas produced from waste materials could meet between 5 -18% of the UK's existing gas needs by 2020. As for shale, many experts think it won't reach peak production until the 2030's – right when we are meant to be scaling back on our gas use – and nobody knows how much gas it would supply.

Will it help the economy?

Shale gas will not help the economy if the UK is serious about tackling climate change. No-one knows for sure, but a report by Bloomberg suggests that UK shale is likely to be far more expensive to extract than it is in the US. At the same time if the world acts to tackle climate change, and so cuts down on its use of fossil fuels, then some analysts, including the IEA, think the gas price will stabilise. Big investments in expensive new fossil fuel resources may simply prove the wrong economic bet. If the price of gas is lower than the cost of getting it out, projects will make a loss. The IEA warns that:

> *"Countries vulnerability to this risk [of stranded assets] may be greater if their asset base is more heavily weighted towards [fields] that are not yet developed and towards those that have the highest marginal production cost".*

That could well include UK fracking.

Even in the US the economics of shale are not working out well for investors – as Shell's chief executive recently put it "unconventionals did not exactly play out as planned." If the economics don't add up there will not be the cut of profits promised to the Chancellor and local communities. Furthermore, the UK government has already promised shale drillers "the most generous tax regime in the world."

For further details on recent reports on the economics of shale, see p23

Will it lower my bills?

When one analyst Bloomberg looked at the likely cost of getting gas out of the ground in the UK they found it wasn't very different to the current price of gas, which makes it hard to see how it could reduce bills. This argument has been countered, but most analysts agree that because the UK is part of a European gas market the impact of UK shale will be limited. Indeed shale explorer Cuadrilla asked Poyry to take a look at how much production from Lancashire could reduce bills and their analysis implies a cut of 0.7-1.8% for households. A spokesperson for Cuadrilla has been recorded stating that the impact of UK shale on bills will be "basically insignificant."

If the economics of fracking are shaky and it doesn't cut bills, then it is likely to create fewer jobs. On its own website Cuadrilla quotes a Regeneris study which suggests its operations in the Bowland shale would create 5,600 jobs with just 1,700 of those in Lancashire. But most of those jobs are unlikely to be available within a few years, with just 200 jobs created from 2022 onwards. A study paid for by Cuadrilla suggested 74,000 could be employed, but that used labour intensive North Sea Drilling as a model. Poyry gave a similar number to parliament but warned:

> *"A lot of things could happen in the process to delay that further — it depends on lots of things going well."*

Meanwhile early reports of a study done by AMEC for DECC report that at peak shale gas will create 15,900 to 24,300 full-time equivalent jobs – direct and indirect – at "peak construction", all of which will typically be short term jobs.

How much drilling will it need?

Fracking is an industrial process requiring large numbers of wells. A report by the Institute of Directors (IOD) for Cuadrilla suggests that UK shale could replace declining production from the North Sea (about half of UK demand) with around 1,000 wells spread across 100 drilling sites producing between 853-1389bcf (billion cubic feet) worth of gas, just under half of UK demand. But that relies on some pretty ambitious (and untested) assumptions. A independent study by Bloomberg found that to meet North Sea production levels (1,460bcf) and sustain it for ten years would need 10,000-20,000 shale gas wells, with around 1,000 wells drilled a year at peak production.

And water?

The Institute of Directors calculates in its report for Cuadrilla that water use from fracking would peak at around 5.4 million cubic metres a year, or around 14,700 cubic metres a day. That's the water use of around 98,000 people – twice the population of Lancaster.

Water UK's policy advisor, Jim Marshall has warned that fears over water use should not be downplayed:

> *"OK in the North West there isn't likely to be a problem, but in the South East water stress is a real concern. Last year we came off the back of three dry winters and low groundwater levels induced drought and water restrictions."*

The situation could get worse as the climate changes. A report by AEA Technology for the European Commission warned:

> *"Areas already experiencing water scarcity may be affected especially if the longer term climate change impacts of water supply and demand are taken into account."*

Drilling firms are likely to pay less for their water than the residents nearby according to a Bloomberg news report in which Richard Davies, director of the Durham Energy Institute at Durham University in England, commented:

> *"Water supplies are crucial to drillers. Fracking one well requires 5 million gallons on average, or enough to fill seven Olympic-sized swimming pools. The amounts used depend on the number of fractures and the length the wellbore travels horizontally into the reservoir rock."*

Will there be other local impacts?

One of the most significant local impacts of fracking will be the volume of truck movements and possibly new roads to carry them. According to the report Cuadrilla commissioned by the Institute of Directors (IoD),

> *"Assuming truck movements are concentrated in the early years of drilling activity, this averages out at 6.1-17.1 per day over five years [for each well pad]. Spread over their estimated 100 well pads that would add up to between 1-3 million truck movements."*

A report by AEA Technology for the European Union estimated that during the most intensive period there could be up to 250 truck movements a day to a single (10 well) drilling site.

Liquids seep into the ground around tanks at a fracking site in Colorado. *Robert Myers / Greenpeace*

What are the risks to the local environment?

Fracking involves the use of large volumes of water alongside chemical additives, so the main risk is contamination of the local water or air through releases of methane or volatile organic compounds.

The UK Environment Agency (EA) risk assessment for shale gas identified high risks of pollution serious enough to cause a breach of an environmental standard with an impact on the local population or surrounding environment. It identified leaking of chemicals in fracking fluid, overuse of water supplies, the leakage of chemicals during storage, transport or mixing – but said all these risks would be minimised by existing regulation.

Few experts think water is likely to be contaminated through the fractures deep under ground. Instead the risk comes from problems with the well, or in the storage and transportation of the waste fluids and materials. Well problems can also allow gasses to escape.

In addition to the chemicals added, the fluid interacts with the formations it is injected into. According to the EA flowback fluid from the Lancashire shale contained

> *"Notably high levels of sodium, chloride, bromide and iron, as well as higher values of lead, magnesium and zinc compared with the local mains water that is used for injecting into the shale."*

It also contains Naturally Occurring Radioactive Materials (NORM).

Whether or not water has been contaminated by shale gas drilling in normal operations is fiercely contested and it is clear more research is needed. A 2011 report by the New York Times found that most US waste processing facilities

> *"Cannot remove enough of the radioactive material to meet federal drinking-water standards before discharging the wastewater into rivers, sometimes just miles upstream from drinking-water intake plants."*

A 2013 study by scientists at Duke University reportedly found dangerous levels of radioactivity and salinity at a shale gas waste disposal site near Blacklick Creek in Pennsylvania. The study's authors said:

> *"If people don't live in those places, it's not an immediate threat in terms of radioactivity. However, there's the danger of slow bio-accumulation of the radium. It will eventually end up in fish and that is a biological danger."*

In Pennsylvania researchers at the same university detected elevated levels of methane, ethane and propane in groundwater samples near active fracking sites. The samples matched the chemical properties of the methane being extracted, though they couldn't conclusively prove it was the result of drilling. A peer reviewed study by the University of Texas published the in Journal of Environmental Science and Technology found elevated levels of contaminants including arsenic, barium, selenium and strontium in private water wells closest to shale gas activities in the Barnett Shale, Texas. The study team argued though that the arsenic probably didn't flow from the fracking itself but rather from the pipes of water wells disturbed by the process.

Drilling can also disturb local wildlife. Drilling by Cuadrilla in Lancashire has been delayed and cancelled due to the presence of birds wintering near the Flyde Peninsula.

What about accidents?

What is less contested is the risk of something going wrong. As Alberta's Energy Resources Conservation Board (ERCB) spokesman Darin Barter warned:

> *"There is no amount of regulation that can overcome human error."*

According to a study by the United Nations Environment Programme (UNEP)

> *"Spills or leaks can … occur during the transport, mixing and storage of the water and flowback."*

This was in response to an incident in which workers from Crew Energy and GasFrac accidentally fracked directly into an underground water table in Grande Prairie, Alberta, in September 2011. The firm is one of a number who have been implicated in spills and accidents impacting on water and the local environment, as reported by Texas University.

In September 2013, more than 40,000 gallons of oil and an unknown amount of waste drilling water leaked from sites in Colorado because of floods. In July 2013, XTO Energy – a division of ExxonMobil – reached a settlement with US regulators to pay $100,000 and spend millions to upgrade existing facilities after a 2010 spill of toxic wastewater in Pennsylvania. They are now being sued by the federal government. In 2009 in Caddo Parish, Louisiana, 17 cattle were found dead near a drilling site. Louisiana regulators concluded that fracking fluid leaked from the well pad and ran into an adjacent pasture. The private companies involved were reportedly fined $22,000. The Times reported in 2013 that two senior US politicians have urged Congress to investigate spills from fracking sites.

Have there been health impacts?

Whilst the potential risk to health is clear it's less certain whether people (or animals) have been actually harmed by fracking, not least due to a number of secretive gagging clauses. There is no overview of the number of gagging orders on families but it has been reported as "typical in settlements reached between oil and gas operators and residents in…. Pennsylvania."

For example, in 2013 it was revealed that two children, aged seven and ten, from Pennsylvania were subject to lifetime gagging orders as a result of a $750,000 settlement between their parents and a leading oil and gas company. The Hallowich family had earlier accused oil and gas companies of destroying their 10-acre farm in Mount Pleasant, Pennsylvania and putting their children's health in danger. Although this case generated significant press attention because the gagging of children was seen as exceptional, it is reported that "at least six such cases have been known in the U.S."

In the same year US online magazine Mother Jones reported that under a new law, doctors in Pennsylvania can access information about chemicals used in natural gas extraction – but companies will be able to prevent them sharing it with their patients. Two US studies have indicated contamination of air quality around shale gas drilling sites, although they have not shown a direct link to drilling.

A 2012 study by Colborn et al indicated high levels of non-methane hydrocarbons in the air around the drilling phase. Of over 50 non-methane hydrocarbons (NMHCs) near shale gas wells, 44 have health impacts including 35 which affect the brain and nervous system. However, the study did not show that residents had suffered adverse health impacts.

A separate study from the Colorado School of Public Health reported in Businessweek found that air pollution caused by fracking may contribute to acute and chronic health problems for those living near natural gas drilling sites. The authors noted that the risks were at a very low level (around 1 in 100,000 cancer risk for those less than half a mile from the well) and therefore called for further study of the health impacts of shale gas extraction before drawing conclusions.

A review of the evidence up until December 2012 by Public Health England noted that air quality could be impacted by fracking through the release of volatile organic compounds (VOCs) and pollutants including particulate matter, nitrogen oxide, sulpher dioxide and ozone.

The paper noted that studies had found pollution often arose from poor industry practice or poor regulation as well as the cumulative impact of drilling – especially emissions from pumps, condensers and trucks.

It argued that whilst the individual impact of any one well would be small, "the cumulative impact of a number of well pads may be locally and regionally quite significant."

The authors called for "comprehensive environmental monitoring" of shale gas operations including monitoring of local air pollution levels. The study also noted that health impact assessments (HIAs) may be appropriate once fracking reached commercial levels. In its analysis PHE concluded that

> *"the risks to public health from exposure to the emissions associated with shale gas extraction are low, if the operations are properly run and regulated."*

A 2012 Cornell peer-reviewed study (Bamberger et al) warned that livestock near fracking sites were falling ill and experienced neurological, reproductive and acute gastrointestinal problems after being exposed – either accidentally or incidentally – to fracking chemicals in the water or air, often due to leaks and spills. The authors – who looked at the leak that caused the death of 17 cows in Louisiana as part of their study – accept the research could not prove a direct link to fracking, but argued this was largely due to non-disclosure by the industry.

And earthquakes?

Fracking has caused minor earthquakes in Lancashire because fluid entered between naturally occuring faults underground, but whilst these may pose environmental risks if they cause pipes to leak they are unlikely to cause large surface impacts. However, a recent study by Columbia University found that the process of re-injecting waste water into the ground may come with higher risks.

The Columbia study concluded that waste-water injection could put stresses on faults which are then triggered by large earthquakes further away – in the case of the US as far away as Chile. Amongst the tremors researchers examined was a magnitude 5.7 quake near the US town of Prague, Oklahoma, which was preceded by a 5.0 shock and followed by thousands of aftershocks.

Can't regulations deal with this?

The UK Environment Agency argues that all these risks can be reduced by planning regulations. However, as the Gulf of Mexico oil spill has shown, regulating away accidents, spills and failures has proven hard. Fracking is especially difficult because it involves thousands of wells and huge volumes of water and chemicals. The concerns are particularly acute because so much of the monitoring is left to the companies themselves and (perhaps not coincidentally) the regulators of shale gas drilling are often under budgetary pressures.

2. Fracking: The evidence

i. What is fracking?

Fracking – or hydraulic fracturing – is a way of extracting oil or gas from the ground. It typically involves the injection of water, sand and chemicals into the rock formation at high pressure to split apart the rocks and enable the oil or gas to flow up the well (along with some of the water, so-called 'flow-back fluid'). In its modern form it is normally used alongside so-called 'horizontal drilling', in which the well is turned sideways through the rocks containing the gas or oil.

Whilst fracking has been employed in one form or another for decades – mostly to prolong the life of existing conventional oil and wells – it has more recently been adapted and its use transformed (credited to an oil engineer and entrepreneur called George Mitchell) to enable the extraction of large reserves of so-called 'unconventional' oil and gas. It's this technological change which enabled the US 'shale revolution'.

Rather than being located in highly porous rocks (a reservoir or oil field), these relatively new reserves tend to be harder to reach. The rocks are often less permeable or the gas is trapped within layers of shale, coal or other rocks. In short, the oil or gas does not simply flow up the well – even at the start of the process.

Oil companies in the UK plan to use a mixture of fracking and horizontal drilling to extract oil and gas from unconventional reserves. This includes gas and possibly oil trapped in shales and low permeability sandstones and limestones, or gas trapped within coal. For all three of these types of resources the process is similar. The well does not simply go down, but turns sideways to work its way along the rock formation containing the gas or oil. That formation is then fracked along the length of the bore, normally using larger volumes of water than were previously required. The process is called 'high volume fracking'.

For some unconventional formations – such as coal bed methane – gas can sometimes be released simply through horizontal drilling, depending on the formation. In short fracking unconventional reserves generally requires many more wells because even with fracking the wells are much less productive than conventional wells. This in turn has implications in terms of quantities of chemicals and water used in the process and produced as waste. Both are higher than for conventional gas wells. Because this process significantly increases the water and drilling required it also increases the impacts (such as trucks to carry the water) and risks (such as water spillages) compared to fracking of conventional oil wells.

High volume fracking, with horizontal drilling, is new to onshore drilling in the UK. A letter from a the Department of Energy and Climate Change (DECC) to a Balcombe resident stated:

> *"Cuadrilla is the only operator in the UK to so far use high volume hydraulic fracturing – this technique was used on the Preese Hall well in Lancashire in 2011. DECC has not at this stage received any applications from other operators to carry out hydraulic fracturing for shale gas onshore in the UK and therefore no such consents have been issued."*

This explains the difference between what has happened in the UK before (it is claimed that 200 wells have been fracked) and what is now proposed. Fracking has taken place, for example, at the conventional oil field of Wytch Farm. But as a spokesperson for the company explained in 2013, that was not high volume fracking:

> *"We believe that the current public concern about 'fracking' relates to extensive, high pressure, hydraulic fracturing using high-volumes of liquid in very low permeability rock to extract gas from shale, and methane from coal-beds. High volume hydraulic fracturing of this type has not been carried out at Wytch Farm."*

ii. Climate

Carbon limit

Research by the International Energy Agency (IEA) suggests that nearly half of the world's proven gas reserves need to be left in the ground between now and 2050 if we are to avoid catastrophic climate change. The research includes not only a significant switch from coal to gas for power generation but also the widespread deployment of Carbon Capture and Storage (CCS) technologies. Should this technology fail, the IEA suggests, even more gas and oil may need to be left in the ground.

Proven gas supplies mean those which have been discovered and are known to be extractable at an economically viable cost. The IEA estimates that the world has about 190 trillion cubic metres of such 'proven' gas – enough to meet current demand (of approximately 3.3 billion cubic metres) for six decades. But when all technically recoverable gas supplies found so far are taken into account there is already 250 years worth of gas – again at current demand. Looking only at conventional gas the world has more than 100 years worth of technically recoverable supplies. No technically recoverable shale gas has so far been found in the UK, and UK shale gas is therefore not counted in either the technically recoverable or proven reserves (technically and economically recoverable) statistics.

Almost half the gas we can afford to burn over the next two decades comes from fields already in production leading the IEA to warn that

> *"In the case of oil and gas fields that have yet to start production, or have yet to be found, the lower level of demand in the 450 Scenario [2 degrees of global warming] means that fewer of them justify the investment to bring them into production (or to find them) before 2035."*

A report by oil and gas consultants Rystad energy for the Norwegian government using IEA data from 2012 suggests gas prices will be higher past 2030 with less gas stranded. The conclusion, however, is based on an assumption of significantly lower gas production over the next three decade. The report still identified expensive gas – such as some gas from the Norwegian Barents Sea – as not compatible with staying within carbon budgets. The same may apply to UK shale.

In absence of production cost data (as UK shale is not economically proven) it appears highly implausible that increased gas production in the UK would prevent the use of existing gas – or coal – resources elsewhere in the world. In fact, the IEA and Ernst and Young both forecast that UK/EU shale gas production will be relatively expensive in comparison to conventional extraction and US shale gas.

In a submission to Parliament Bloomberg noted that estimated extraction costs in the UK would be between 40% and 100% higher than the US. Indeed, looking at fossil fuel use as a whole a report by the UK government's chief scientist concluded that in absence of a binding global deal more fossil fuel extraction in the UK would only increase global emissions, accelerating climate change. The report concludes:

> *"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. This increase would work against global efforts on climate change. In the absence of global climate policies, we believe it is credible that shale-gas use would increase both short-term and long-term emissions rates."*

The authors suggest that global climate policies, if agreed, may mitigate shale gas production through

> *"carbon capture and storage; carbon offsetting through additional reforestation or negative emissions technologies that reduce CO2 concentrations."*

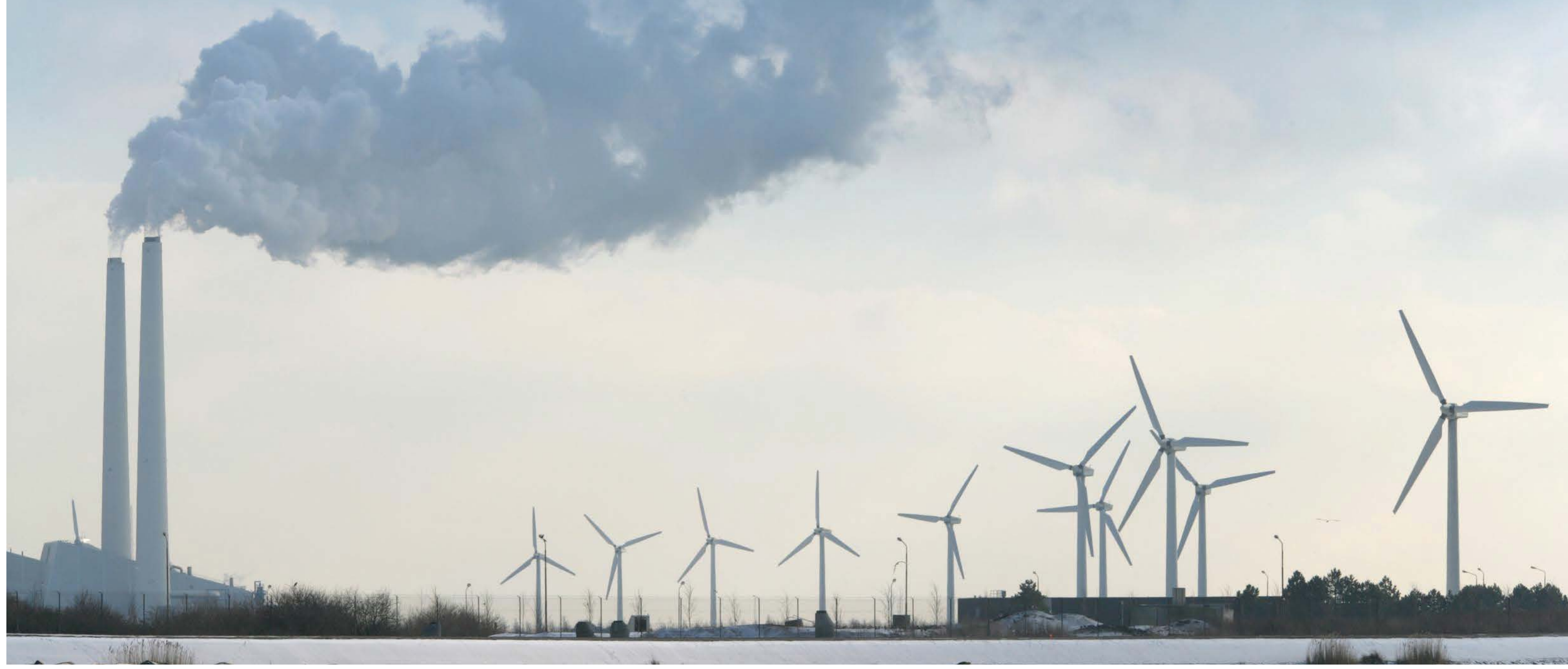
None of these methods are yet proven.

The analysis by the IEA, Bloomberg and professor Mackay could suggest that UK shale gas production – in absence of a global climate deal – is actually premised on an assumption that global efforts to tackle climate change will fail resulting in high global demand for gas and fossil fuels in general. Thus the creation of a shale gas industry requiring a high gas price is the creation of a business lobby requiring for its profitability that oil and gas extraction continue regardless of climate impacts.

UK Carbon budgets

A study by the Tyndall Centre, Manchester, estimated that if we were to burn 20% of Cuadrilla's original estimated resource in the Bowland shale that alone would account for almost 15% of the UK's legally binding carbon budget. This figure is based on a translation of the Cuadrilla resource to an "ultimately recovered" estimate given stylised growth and decline, so only 88% of that was recovered by 2050 in the Tyndall Centre's scenario. Technically the "15% of the carbon budget" is therefore 17.6% of Cuadrilla's estimated resource.

Taking a simpler approach, and following advice from the researchers involved, it is possible to calculate the impact of the 2013 British Geological Survey shale gas resource estimate on the UK's carbon budgets. If the UK were to burn 10% of the available shale gas resource identified by the British Geological Survey in the Bowland-Hodder shale, the CO2 produced would occupy more than 80% of our remaining carbon budget to 2050. That is to say that if combusted, 10% of the BGS Central estimate of 37.6 tcm gas in place, would occupy 93% of the cumulative CO2 emissions remaining within the CCC's Intended Pathway (2014 to 2050) or 83% of the Interim Pathway. It should be noted that lower levels of recovery than 10% are very plausible.[2]



Methane leakage and soot

The above calculations are based on the assumption that shale gas extraction has few additional climatic impacts – beyond burning the gas to produce energy. However some research suggests that because burning gas produces fewer particulates than coal (generally seen as a good thing in environmental terms) it may have worse short term climate impacts. Research quoted in the New Scientist suggested that over the medium term at least simply replacing coal with gas may be worse for the climate than sticking with coal.

Tom Wigley of the National Center for Atmospheric Research in Boulder, Colorado, concluded in a recent study that substituting gas for coal increases rather than decreases the rate of warming for many decades because the carbon benefits of gas are not sufficient to outweigh the short term climate cooling impact of soot from coal. If it escapes into the atmosphere uncombusted methane is itself a more potent greenhouse gas than the carbon dioxide over the short and medium term. Methane can be released through the well borehole itself or through storage of flow-back water at the surface. Some releases are intentional - e.g. when gas is vented, in other cases it results from leaks e.g. through valves. In its environmental impact assessment for shale gas the Environment Agency identifies a high risk of releases, however it argues it's regulatory measures can minimise these risks.

A study published in April 2013 by scientists at the Environmental Defence Fund (EDF) and Princeton University in New Jersey suggests that shifting to natural gas from coal-fired generators has immediate climatic benefits as long as the cumulative leakage rate from natural-gas production is below 3.2% from well to city. This figure depends, however, on a range of factors including assumed power plant efficiency and the potency of methane. A report for the European Commission has suggested that even with expected leakage shale gas extraction is better than coal, but suggested shale gas may be worse than pipeline gas – such as gas from the North Sea.

In is most recent update the Intergovernmental Panel on Climate Change (IPCC) increased its estimates of the potency of methane. The IPCC now believes methane is 86 times more potent than carbon dioxide over a 20 year time horizon (up from 72) and 34 times worse over a 100 year time horizon (up from 20).

The climate impact of methane, however, is only relevant if it leaks in sufficient quantities. Atmospheric studies in Colorado carried out by the US National Oceanic and Atmospheric Association (NOAA) suggests between 4% and 9% of the methane extracted was released into the atmosphere – enough to seriously erode or remove the climate benefits of burning gas over coal. However the studies have been criticised in a peer review paper by Michael Levi from the US Council on Foreign Relations. A wider study by the Massachusetts Institute of Technology (MIT) based largely on industry data suggested emissions were a fraction of those suggested by NOAA.

A 2013 review of the evidence by the UK government's chief scientific advisor and a 2013 field study by the University of Texas both suggested that should tough regulations be applied and followed, leaks can be significantly reduced (though not completely eliminated). It also identified some new potential pathways for methane release (on a small scale). The study looked primarily at emissions from relatively new wells which carried out "green completions" to reduce leakage rates, a technology the US Environmental Protection Agency is in the process of making mandatory. The EPA's standards will apply to storage tanks over a particular size and will be phased in for new fracking in 2014. Similar rules are expected to be applied in the UK.

An older report by-the UN environment agency had concluded that gas can only be shown conclusively to be better for the climate than coal over a 100 year time horizon. Recent studies by Boston academics have suggested another source of fugitive emissions – through ageing pipeline infrastructure – a factor which may well prove important in the UK. The 2013 DECC/Mackay review warns:

> *"It is important to note that there has been little measurement of direct or indirect methane emissions from shale gas exploration and production anywhere in the world. Outcomes of LCAs (life-cycle assessments) therefore carry some uncertainty."*

It also advises caution extrapolating from US experiences.

It therefore seems reasonable to conclude that whilst measures have been proposed and implemented to reduce methane emissions from fracking there remains a risk of climate impacts from this source. This risk would be increased in the event of companies failing to comply with best practice or self-regulation. Because over the longer term burning coal is still worse for the climate than gas the research above does not suggest that it is preferable. Due to the carbon emissions released by burning gas (from any source) the UN report concludes:

> *"Ultimately the question of coal-to-gas substitution is a misguided debate, as none of the scenarios leads to satisfying results to limit global warming."*

3. Shale gas and imports

If the UK maintains strong climate change policies gas demand is projected to fall. The UK's legally-binding Climate Change Act requires that emissions must fall by 80% on 1990 levels by 2050. Because emissions in the aviation sector will not fall sufficiently emissions in other sectors including power, buildings and industry must fall by more. In particular the government's Independent Committee on Climate Change (CCC) advise that the most cost-effective decarbonisation pathway is for the power sector to be almost carbon free by 2030 and UK households must be almost entirely gas free by 2050. Gas use for heating and industry should also fall.

Though exact numbers are not available, there are various scenarios. Guidance provided to Greenpeace by the CCC and analysed alongside data from the Department of Energy and Climate Change and other sources suggests that UK gas demand will fall by approximately 30-45% by 2030 and by 60-75% by 2050, depending on barriers to replacing gas use. The estimated forecasts from the CCC include gas use for Carbon Capture and Storage projects and represent working numbers – subject to change – rather than a firm forecast or policy recommendation.

However the analysis is reinforced by the data from the National Grid's 'Gone Green' scenario recently quoted in the Navigant report for DECC. This report notes that DECC's own gas use forecasts exclude the policy measures set out in the low-carbon transition plan and suggest that – excluding exports – UK gas use will fall by over 40% by 2030, in line with the estimates above. Taken alongside projections of UKCS (United Kingdom Continental Shelf) North Sea gas production the analysis suggests action to reduce emissions would see UK net gas imports fall between now and 2030 and fall further through to 2050 – even without shale gas development.

A study by the National Grid based on an analysis by Ernst and Young found that biogas produced from waste materials could meet between 5-18% of the UK's existing gas needs by 2020. When combined with falling demand this would significantly compensate for falling North Sea production. Falling demand and increased supply from biogas would reduce UK imports to around half their current level by 2030 (assuming estimates of North Sea production prove accurate). Analysts quoted by Reuters suggest this demand (as opposed to the published DECC forecast referenced which ignores climate change policies) could be met by Norwegian North Sea pipeline supply without relying excessively on LNG (Liquified Natural Gas) shipments. In the longer term the UK could invest in technology to produce gas from wind and other renewable sources currently being researched in Scotland and with pre-commercial plants already running the key technologies in Germany and Denmark.

A study by the National Grid suggested imports could be higher even in their 'Gone Green' scenario. This finding is based partly on an assumption that imports would be needed to make up for continued UKCS gas exports. It also assumes no increase in North Sea pipeline capacity from Norway.

Greenpeace analysis suggests that UK shale gas production will come on stream just as UK gas demand falls. An illustrative scenario by the Institute of Directors suggests UK shale gas production will peak (matching current North Sea production) in the mid 2020s. A study by Poyry for Cuadrilla puts the production peak around 2035, after the UK power sector has decarbonised and with gas use for heating on the wane. A report for DECC by Navigant suggests UK shale gas production will peak at 2030 and even then at only around 5% of current demand. It should be noted that Norwegian pipeline gas supply does not incur significant emissions in transport.

4. Economics: Fracking

i. Fracking and the economy

The British Geological Survey suggested the UK has a very significant shale gas resource (1300tcf), however, a similar study by the US Environmental Information Agency (EIA) concluded that once risks are factored in only around 4% of the UK's resource was likely to be technically recoverable – a measurement described as the "best tool available" by one UK academic. To put this in context, 4% of the UK's resource (52tcf) would only be marginally more than the proven gas reserve in the North Sea in 1999 – so its significance should not be exaggerated. But crucially this 'recoverable' number does not take into account the economics of shale gas extraction, which academics at the UK Energy Research Centre suggest could reduce the extractable volume still further – depending, of course, on the market price.

Even in the US the price of gas does not wholly reflect the cost of extraction. Shale gas came onstream amidst a boom of investment as the country's economy and therefore demand stagnated. It had too few easy-to-access export markets. As the CEO of Exxon put it, US firms are "losing their shirts" on shale. More recently Shell's chief executive Peter Voser said "unconventionals did not exactly play out as planned". The firm recently announced a $2.1bn impairment on the book value of its unconventional assets.

Furthermore UK shales are geologically very different to those in the US. They are deeper, thicker and more complex. The US Energy Information Administration (EIA) concluded:

> *"Compared with North America, the shale geology of the UK is considerably more complex, while drilling and completion costs for shale wells are substantially higher... faults are numerous, geologic data control is weak, and shale wells are more costly to drill."*

The agency adds that measures put in place by the UK government to limit the risk of earthquakes and water pollution will also add

> *"significant cost and time to drill shale wells in the UK."*

Attempts to exploit Polish shale resources, which are also largely deeper than those in the US, have so far failed to yield significant results. Since the drilling started the gas in place estimates have been revised down (including by the US EIA) and three energy giants, Exxon, Marathon and Talisman Energy have quit.

The differences between the UK and the US may not just increase the cost of extraction, it could also delay peak production. An executive at BG group told the FT:

> *"Our position is that you've seen a tremendous change in the US and the US was, really, in terms of developing unconventional, a sweet spot. Our view is that we're sceptical that's going to be fully replicated anywhere else as quickly as we've seen it in the US."*

In the US an estimated 80,000 wells have been fracked in the state of Ohio alone. Current plans for the UK would see around 40 individual wells (as opposed to well pads) over the next few years - which is unlikely to make any significant impact on UK production (especially as they are largely exploratory).

An illustrative scenario for Cuadrilla by the Institute of Directors suggests UK shale gas production will peak (matching current North Sea production) in the mid 2020s. A study by Poyry for Cuadrilla puts the production peak around 2035 whilst DECC's Navigant study puts it at 2030 (at low levels). This means any economic benefit is extremely unlikely to be felt over the short term. The IEA, Bloomberg and Ernst and Young have forecast UK/EU shale gas production could be comparable in cost to the current wholesale cost of gas (50-80p/therm).

Indeed it is quite possible – given the experience in Poland – that UK shale gas will prove more expensive than gas imports and that large-scale production will never take place, even after significant investment in technologies and disruption to communities during the exploration phase. Even at current gas prices Bloomberg notes:

> *"This [the cost of gas extraction] suggests that even proven shale gas resources in the UK might struggle to secure finance."*

In a 2013 submission to Parliament Bloomberg added:

> *"Extracting gas from shale in areas such as the Bowland basin in northern England would cost $7.10 to $12.20 per million British thermal units compared with $5 to $6 in the U.S. The greater cost, because of higher land prices and lack of rigs and infrastructure, is close to the $8-to-$11 range in which U.K. spot prices have traded in the last two years."*

The IoD chose to ignore the higher range of these forecast price points focusing on the lower range of the analysis from Bloomberg and the Energy Contract Company, which would put shale gas production around 40-50p/therm, and thereby profitable at today's gas prices. A report by the Joint Research Centre for the EC also had a slightly lower range. But assuming the world takes action to tackle climate change this means UK shale gas will come on stream just as the IEA predicts that the world's already proven supplies of gas – along with cuts in global fossil fuel use – are beginning to push down prices. Indeed the IEA predicts that gas use for the power sector will have peaked worldwide before 2030.

The IEA has published new EU gas price forecasts assuming global action to tackle climate change. These suggest wholesale gas prices for the EU would be similar to or lower than 2011 and may be below the UK cost of shale gas extraction as forecast by Ernst and Young and Bloomberg, leaving shale gas assets in the UK either stranded or in need of financial support. Navigant, in its report for DECC which does not assume action to limit climate change, forecasts gas prices remaining at their current levels through to 2030, or rising if global unconventional gas extraction fails to deliver. In either scenario shale gas extraction in the UK may struggle economically, depending on final production costs.

In its report for the Norwegian government Rystad Energy suggests higher gas prices within global carbon budgets – due to a shortage of supply relative to the IEA. However the consultants, like the IEA, also assumed the widespread roll-out of CCS for gas, a technology which has yet to prove itself viable or economic and their report still warned that high cost gas extraction may not be viable. In conclusion the IEA warns:

> *"Countries vulnerability to this risk [of stranded assets] may be greater if their asset base is more heavily weighted towards [fields] that are not yet developed and towards those that have the highest marginal production cost".*

There is evidence to suggest UK shale may fit both of those criteria – depending on final extraction costs.

The IEA and others have also warned that global shale gas activities could be at risk from water stresses or flooding resulting from climatic change, whilst increased adverse weather conditions could threaten North Sea oil supplies.

Tax receipts from shale gas may also be limited by the overall economics. The Treasury has already announced "the most generous [tax regime] in the world" for UK shale gas extraction, reducing the tax rate to 30%. The UK government has also promised that 1% of revenues from shale gas extraction will go to local communities. Tax benefits will only accrue, however, if and to the extent that shale gas extraction in the UK is profitable – if extraction costs are lower than the price of wholesale gas. The analysis above suggests this is not a given.

In short allowing unchecked shale gas exploration could leave the UK economy over-dependent on fossil fuel extraction and over-exposed to the economic impacts on the fossil fuel industry of global action to tackle climate change. The situation in Poland, where an industry has already moved into reverse simply because Polish gas is not economic at current prices, is a warning of the economic risk of UK shale.

ii. Bills

There is very little evidence to suggest that shale gas extraction from the UK will work to reduce bills for consumers. The UK is part of a global gas market and as such increases in supply – be it in the North Sea or Lancashire – are unlikely to have more than a relatively marginal impact on bills for households, especially at the levels of production which are likely.

In its report to parliament Bloomberg argued:

> *"Our conclusion is that even under the most favourable case for shale gas production, with production reaching 4.5bn cubic feet per day (around half current demand) in the mid-2020s… the UK will not be self-sufficient in gas. The reliance on continued imports will ensure that UK gas prices remain tied to European and world markets and so the direct impact of shale on the cost of electricity in the UK will be limited."*

An illustrative scenario by the Institute of Directors suggests UK shale gas production will peak (matching current North Sea production) in the mid 2020s (as suggested in Bloomberg's best case). However a technical study by Poyry for Cuadrilla puts the production peak around 2035, after the UK power sector has decarbonised, and with gas use for heating on the wane. A report for DECC by Navigant suggests UK shale gas production will peak at 2030 and even then at only around 5% of current demand.

Taking the impact on the European market into account the Poyry report examined in detail by Energydesk suggests that Cuadrilla's production forecasts (as provided to Poyry) would reduce gas prices by between 2-4%. This equates to an impact on bills of 0.7 to 1.8%, though as decarbonisation and efficiency progresses this may be lower still. A report by the Institute of Directors commissioned by Cuadrilla suggested the impact on bills was unknown. A spokesperson for Cuadrilla has been recorded stating that the impact of UK shale on bills will be "basically insignificant."

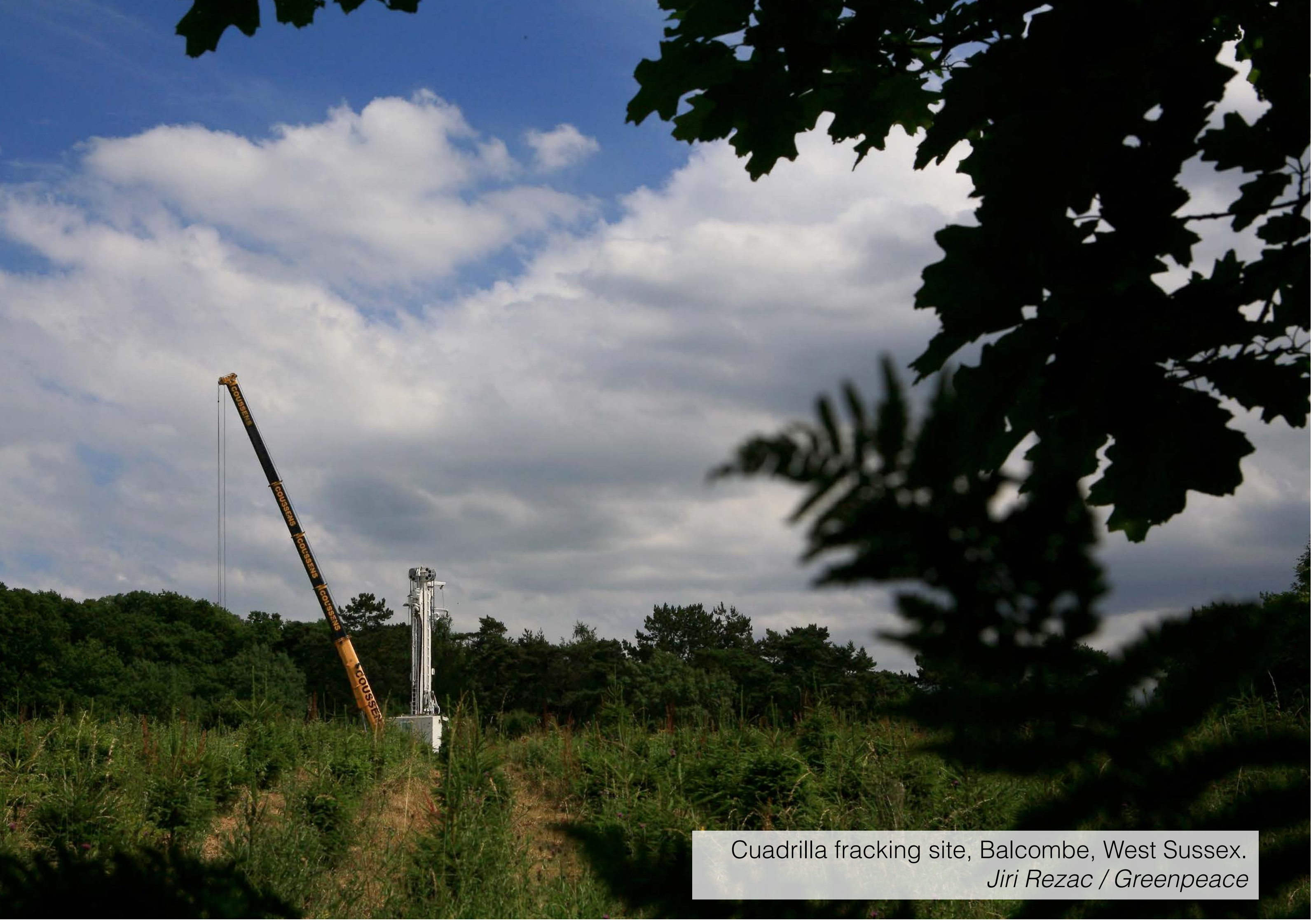
It is important to note that whilst there is almost no evidence UK shale gas will have a significant impact on bills, global shale gas – along with global gas reserves more generally – could moderate bills, especially in the context of global action to limit climate change. Indeed action on climate change should be seen as likely to promote lower gas bills over the short term by reducing demand.

The Navigant report for DECC suggests UK bills are likely to remain flat or fall slightly assuming large-scale development of shale gas in China. The IEA predicts gas prices for the EU will rise over the next decade by around 10% before returning to current levels should there be global action to limit emissions to two degrees of global warming. The agency still warns however that the cost of gas will rise by 30% (on 2011 levels) should the world not act to limit warming to two degrees. Global shale gas, however, is unlikely to be necessary in the context of global action to reduce emissions - given that more than around half of proven gas supplies must be left unexplored. Only US shale so far fits within the proven category – and that is expected to reach peak production over the coming decades.

Furthermore shale gas extraction has yet to take off outside of the US. In France the practice is banned. In Poland most of the firms exploring for gas have pulled out arguing reserves were not economic to extract, and in China where shale gas extraction is threatened by water shortages fracking has barely begun and the country has already missed early targets. Experts at Chatham House have argued geological, economic and political barriers mean repeating US style shale gas extraction elsewhere may not be possible.

iii. Jobs

Because shale gas is unlikely to lower bills it will also have less indirect impact on jobs. Estimates of the direct impact – in the drilling and supply chain sector – are unclear and lack any independent verification. On its own website Cuadrilla quotes a Regeneris study which suggests it's operations in the Bowland shale will create 5,600 jobs with just 1,700 of those in Lancashire. But most of those jobs are unlikely to be available within a few years with just 200 jobs created from 2022 onwards.



Cuadrilla fracking site, Balcombe, West Sussex.
Jiri Rezac / Greenpeace

The Institute of Directors suggests that a scenario which replaces the production of the North Sea with shale gas would support 74,000 jobs. These figures include estimates of supply chain jobs – which may or may not be Full Time Equivalent – and most of the employment is only estimated to last ten years. This calculation is based on estimates of the number of jobs created for each £1m in capital and operating expenditure in the North Sea, and the job creation for capital expenditure for the US.

Not only could it be misleading to compare a mix of capex and opex with just capex but because, as the IOD accepts, the wider economic impact of shale in the US is unlikely to be replicated in the UK, the US is not a comparable. To compare the job impact of capital expenditure in the North Sea with the construction of onshore shale gas could also be inaccurate given how much more labour intensive offshore oil and gas operations may be.

In comments to a House of Lords committee energy consultants Poyry – who had previously compiled a report on shale for Cuadrilla – argued that the industry would "eventually" employ 40-60,000 and many more indirectly (up to 100,000 the Times reported). However, the consultants warned, those jobs would not materialise for at least a decade. John Williams, senior principal at Poyry, said:

> *"A lot of things could happen in the process to delay that further – it depends on lots of things going well."*

The Times reported that production will peak in the 2030s.

Early reports of the study done by AMEC, the engineering consultancy that is advising DECC on the Strategic Environmental Assessment, counter these high estimates. The Financial Times reported that:

> *"AMEC predicted at a private meeting at the DECC offices in Whitehall that 15,900 to 24,300 full-time equivalent jobs – direct and indirect – would be created at 'peak construction' by the shale gas industry. The company told people at the event on September 26 that the jobs would typically be short term, at between four and nine years. AMEC also referred to concerns over job leakage, suggesting that at a previous fracking operation at Preese Hall, Lancashire, only 17 per cent of jobs had gone to local people."*

Any jobs benefits there are would also have to be weighed against possible costs to the local economy of Lancashire including agriculture and tourism. Both risks have been recognised in the US with one agricultural insurer reducing its coverage of fracking related risks and concerns raised about the risks of shale extraction to agricultural production. Northern Rivers tourism authority has also expressed concern about coal seam gas extraction in the region, a similar process to fracking.

US press and the FT has reported that job numbers attributed to shale gas in the US are largely based on assumptions (multiples) which are not supported by the evidence. The paper argues in its Alphaville column that even in the US where prices fell sharply the saving amounts to just 0.2% of GDP and only impacts on 1% of the economy. In short, the paper argued:

> *"Natural gas prices would have to be, and remain, quite low indeed to have a significant economy-wide impact."*

Most experts do not forecast this for the UK, and because shale gas extraction would not start in earnest for at least a decade any jobs benefits would do nothing to ease the current economic predicament.

The beneficial impacts of low energy prices (were they to materialise) on exports have also been questioned. A recent study by the Brussels think-tank Breugel found that during the 1990s and 2000s, power price movements had little influence on European countries' export market shares, but they can affect which sector becomes more competitive.

iv. Ownership

An analysis by Energydesk suggests that relatively few of the UK's shale gas operators are UK owned - indicating the benefits of tax breaks are unlikely to go to UK investors.

Chinese state owned oil firm, CNOOC, holds a stake in I-gas. Igas is one of the largest holders UK drilling rights alongside fellow unconventional gas explorers Dart, Cuadrilla, Viking and Coal Mine Methane firm Alkane. CNOOC is also linked to Cuadrilla's co-owner, AJ Lucas through a Hong-Kong based investment fund.

Update on 2013 Poyry and IEA reports

IEA-WEO 2013

In its latest publication, the IEA updates its gas price forecasts in line with recent movements. Gas import prices for Europe are slightly higher in the short term but slightly lower by 2035 – at $9.5/MMBtu.

It also publishes updated assumptions on its '450' scenario (which gives a 50% chance of avoiding more than two degrees warming) suggesting that OECD (developed nations) gas demand falls between 2011 and 2035 with demand in the EU.

Poyry/Cambridge econometrics

A November 2013 report by Poyry and Cambridge Econometrics for the European Oil and Gas industry found that between 2020 and 2050, shale gas in the EU could reduce average wholesale gas prices by 6% and wholesale electricity prices by 3% (central scenario) over the scenario period with greater savings if the EU experiences a 'shale boom'.

As explained above however, the impact on household bills would be lower than the headline wholesale price change – as wholesale prices make up only around half of the bill.

The report takes a far more long term view than their earlier study (see above) and forecasts almost no price changes as a result of fracking until 2025. The report envisages that after practical and environmental constraints were applied, the UK would have 250–600bcm of shale gas reserves (central to boom scenario), equal to two to five years supply at current demand. However, the authors suggest more supplies can come on stream as practical constraints are removed through to 2050 up to around 1tcm (eight years at current demand).

The report looks at the wider economic impacts of shale in Europe, forecasting an increase in GDP of between 0.3 and 0.8% by 2035 and a reduction of gas import dependency of 11%–27% with the industry creating 4–800,000 jobs around Europe directly and indirectly by 2035. The shale boom scenario envisages 33–67,000 wells.

The report appears to be based on a central scenario which assumes global policies which are not designed to prevent catastrophic climate change (viewed as warming above two degrees).

Though the underlying assumptions in Poyry's central scenario are not made public, the report assumes 40% of power sector demand is met from fossil fuels – with renewables not reaching more than around 40% penetration.

This is at odds with the IEA's 450 scenario (which gives a 50% chance of limiting to two degrees) OECD coal and gas use for the power sector both fall between 2011 and 2035 and together make up less than 30% of power generation. The same scenario puts renewables 49% for the OECD as a whole by 2035 (with the EU likely at a higher level).

The falling demand for gas has an impact on the price with EU gas import prices falling progressively from $11.7/MMBtu in 2012 to $9.5/MMBtu in 2035 (IEA). It is not clear what wholesale price Poyry assumes but its analysis gives a break-even price range for 60% of recoverable shale gas in 2020 as between $8/MMBtu and $11/MMBtu – so slightly under the IEA's current forecast. Bloomberg recently quoted an initial cost of extraction of between $7.5 and $12.2.

The report's central scenario does not appear to forecast significant reductions in EU gas demand over the forecast period. The IEA and CCC (UK only – though the UK is connected to the North European market) both anticipate falling gas demand between now and 2035 – with further reductions likely through to 2050. Indeed the EU Council has set a target of 80–95% reductions in greenhouse gas emissions by 2050, possibly reducing EU demand below forecast shale production levels.

Global action on climate change therefore could reduce, or remove, the economic benefits of shale gas suggested in the study.

The production cost ranges, taken with the IEA's 450 price forecasts suggest it cannot be guaranteed that the marginal cost of production when shale gas comes on stream at scale by 2025 will be below market prices. Though the central production cost forecasts are below central price forecasts the IEA's analysis suggests that these prices will not be maintained. Shale gas will come on stream amidst falling demand and falling prices.

Market developments – such as reductions in the price of Russian gas (which is priced well above its production cost) or imports from the US, could leave shale assets stranded. The authors point to cost reductions due to efficiencies from production – but these reductions depend on production reaching scale in an environment of falling gas demand and weak market prospects.

Lower demand would also reduce the economic benefit of any price reductions achieved through shale gas production in the EU (because the benefits of lower prices would be less) and lower prices – as a result of lower demand – would also reduce the scale of any reductions.

5. Economics: Gas

The IEA's analysis suggests that if the world acts on climate change then gas will not be scarce or expensive – though it will inevitably remain a highly price volatile fuel source. This leaves open the theoretical option that the UK should neither frack (in case the price is too low) nor invest in low-carbon, but rather reap the benefits of lower gas prices from decarbonisation and possibly shale gas exploitation elsewhere. Aside from the duplicity of this position it remains economically flawed to rely on gas for power.

In an environment of global action to tackle climate change carbon prices would increase – as forecast by the CCC – making gas power as expensive as other low-carbon sources over the medium term. Should other countries not act on climate change the UK's shale gas reserves are unlikely to be sufficient to lower the cost of gas for power, which would rise with global markets.

Whilst this would be good for shale gas drillers it would do nothing to make gas power more competitive with low-carbon energy sources or to insulate consumers from gas price shocks.

In the long term though the economic argument against both gas use and shale gas extraction focuses on on the economic impacts of climate change - both in terms of costs (flooding etc) and energy security, as highlighted by the recent IEA report. The IEA states:

> *"In areas of water scarcity, either now or due to climate change the extraction of water for drilling and hydraulic fracturing may encounter serious constraints."*

In the UK shale gas extraction itself would prove more difficult if water stresses or flooding became more common, whilst the North Sea extraction is also at risk from extreme weather, according to the IEA.

6. Shale oil: economic and climate impacts

The UK is also looking at extracting oil from shale. The reserves identified have been called both 'shale oil' and 'tight oil' referring to oil trapped in Micrite layers between the Kimmeridge shales. Cuadrilla prefers to use the term 'tight oil' though many in industry use the two terms interchangeably. No cost estimates have so far been suggested though the warnings on cost given in the EIA report also apply to shale oil (the agency research covers both).

Again the IEA suggests more than around half of already proven oil supplies need to remain in the ground by 2035. In fact the prognosis for oil is even worse than gas – the IEA argue that global oil demand should peak by 2020 – well before substantial new shale oil supplies are likely to come on stream in the UK. Even if the world doesn't act to tackle climate change, the days of ever increasing oil demand appear to be ending, according to The Economist which argues that expensive oil (and oil majors) will struggle. The paper reported:

> *"Bernstein, a research firm, reckons that new barrels of oil from the Arctic or other technologically (or politically) demanding environments now cost $100 to extract."*

A recent report for the Norwegian government examined the impacts of the IEA's analysis on future oil and gas production. The report assumed far lower gas production than the IEA, including much reduced production from shale gas, however, it warned, that long-term gas projects, such as gas from the Norwegian far north or unconventional gas in Europe, could be stranded assets. It also concluded that fracking for tight oil was significantly worse for the climate than conventional oil supplies. Like gas, shale oil would be sold into a global market and so would have no beneficial impact on UK petrol prices and, like gas, revenues to the Treasury and benefits to the UK economy would depend entirely on its (highly uncertain) long term profitability.

7. Social and environmental impacts of fracking

i. Number of wells

The number of wells needed to extract a given amount of gas is fiercely contested – however it is clear that to extract any significant quantity would require hundreds and probably thousands of wells causing disruption as they are drilled and environmental concerns after they are abandoned.

A report by the Institute of Directors for Cuadrilla suggests that UK shale could replace declining production from the North Sea with around 1,000 wells spread across 100 drilling sites producing between 85-1389bcf worth of gas, just under half UK demand.

The report claimed that because the UK's shale was thicker than that in the US each well could effectively multiply by four underground (precedents for which appear to be very rare) and that each and every one of those four 'laterals' could itself extract gas equivalent to the most productive wells in the most productive region of the US, a so-called 'sweet spot' (each lateral extracting 3.2 billion cubic feet worth of gas over it's lifetime).

Precisely because shales in the US are different to those in the UK, this technology is untested and could require very significant up-front investment and financial risk. In the event that Cuadrilla was unable or unwilling to pioneer this technology then this study would instead suggest they would need to drill at least 4,000 wells instead.

In fact, a study by Bloomberg based on average well extraction data (rather than just 'sweet spots') found that to meet North Sea production levels (1,460bcf) and sustain it for ten years would require between 10-20,000 shale gas wells with around 1,000 wells drilled a year at peak.

Bloomberg notes that in its less optimistic scenario for well flow (20,000) the wells would 'drain' an area twice the size of Lancashire. Under that assumption, therefore, achieving North Sea like production from the Bowland region would be implausible.

An analysis by Alan Whitehead MP based on average well extraction data from the US has suggested that to meet a more modest 10% of UK demand over a 50 year period would require between 9,000 and 18,000 wells. To extract 10% of the Lancashire resource – as identified by the British Geological Survey in 2013 – would involve, according to Mr Whitehead, around 110,000 wells. A similar analysis by Energydesk but based on the most productive US wells put the total figure for 10% of the resource at 50,000 wells. However, as explained above, it is geographically implausible to expect this level of extraction.

Wells would be grouped into 'well pads' around the size of a football pitch each of which could accommodate around 6 to 10 wells with associated storage tanks, roads, pipes, truck parking and other infrastructure. This means Bloomberg's estimate of around 10,000 wells could equate to over 1,000 pads, each of which would be subject to more or less constant activity over a number of years. What this means in practice is that the impact of shale gas will be relatively concentrated around the location of well pads, and will therefore cause prolonged local disruption.

ii. Volumes of water

Fracking is an extremely water intensive process. Attempts to roll out fracking across England could therefore be limited by the availability of water, especially in the South.

Water UK, which represents water utilities, has estimated that to drill 1,000 wells would use up to 2 million litres of water a day – equivalent to the daily use of around 13,300 people based on data from the Environment Agency (the average person uses 150 litres of water a day). However this is likely to be a conservative estimate. The Institute of Directors calculate in their report for Cuadrilla that in order to match North Sea gas production (which meets around 40% of current UK demand), water use from fracking would peak at around 5.4 million cubic metres a year, or around 14,700 cubic metres a day. That's the water use of around 98,000 people – twice the population of Lancaster.

The IoD report notes:

> *"A single 10-well pad of 40 laterals could use 544,000 cubic metres of water...Water use could peak at 5.4 million cubic metres per year, with a peak of 50 rigs drilling and fracturing 400 laterals a year, and flowback water could reach 1.6 million cubic metres per year."*

Even that estimate is based on an arguably optimistic assumption about water use and shale gas extraction. The IoD based their calculation on the shallower and thinner Eagle Ford shales in the US, where relatively few wells have been drilled.

The exact amount of water required however, varies per well. The US Environmental Protection Agency (EPA) estimates that the water needed to drill a horizontal shale gas well ranges between 7,600 cubic metres and 19,000 cubic metres. DECC has put the figure at between 10,000 and 20,000 cubic metres.

Water UK has warned that fracking could take place in areas under water stress including pockets of the North and large parts of the South East and South West of England. Friends of the Earth observe that Cuadrilla drilling near Blackpool is within the River Wyre catchment. The Environment Agency identifies that all zones in the catchment are classified as either "over licenced", "over abstracted" or "no water available" – though Cuadrilla would not have to remove water locally. Water UK's policy advisor, Jim Marshall has warned that fears over water use should not be downplayed,

> *"OK in the North West there isn't likely to be a problem, but in the South East water stress is a real concern. Last year we came off the back of three dry winters and low groundwater levels induced drought and water restrictions."*

A report by AEA Technology for the European Commission warned that water problems would be exacerbated by climate change:

"Areas already experiencing water scarcity may be affected especially if the longer term climate change impacts of water supply and demand are taken into account."

The Chartered Institute of Water and Environmental Management says fracking "must not be allowed to conflict with water use for public water supply or that needed to maintain a healthy environment", warning "climate change scenarios predict less water availability in the future so whether this level of water use is appropriate in the long term to source energy requires further research."

Recently 30 communities in Texas found themselves almost without water – including the town of Barnhart where taps ran dry – reportedly due to a mix of drought (linked to climate change) and water extraction for shale gas and oil.

As will be explained in the next section fracking also produces large quantities of waste water which need to be sent for recycling or safe disposal. The IoD estimated flowback fluid of around 1.6 cubic metres per year. A recent report by the campaign group Environment America claimed that fracking in the US generated 280bn US gallons of toxic waste water last year. That's enough to flood all of Washington DC beneath a 22ft deep toxic lagoon.

Fracking firms may also pay less for their water than residents. A report by Bloomberg suggested UK water firms would offer cheaper rates to fracking firms who would benefit from discounts available to industrial users. The report noted that according to Richard Davies, director of the Durham Energy Institute at Durham University,

> *"Water supplies are crucial to drillers. Fracking one well requires 5 million gallons on average, or enough to fill seven Olympic-sized swimming pools. The amounts used depend on the number of fractures and the length the wellbore travels horizontally into the reservoir rock."*

iii. Trucks

Fracking requires thousands of trucks to transport water to and from the drilling site. The IOD estimated that each well pad would require 11,155-31,288 truck movements over 20 years, "depending on whether the water comes from a mains connection or is trucked in." The report added that:

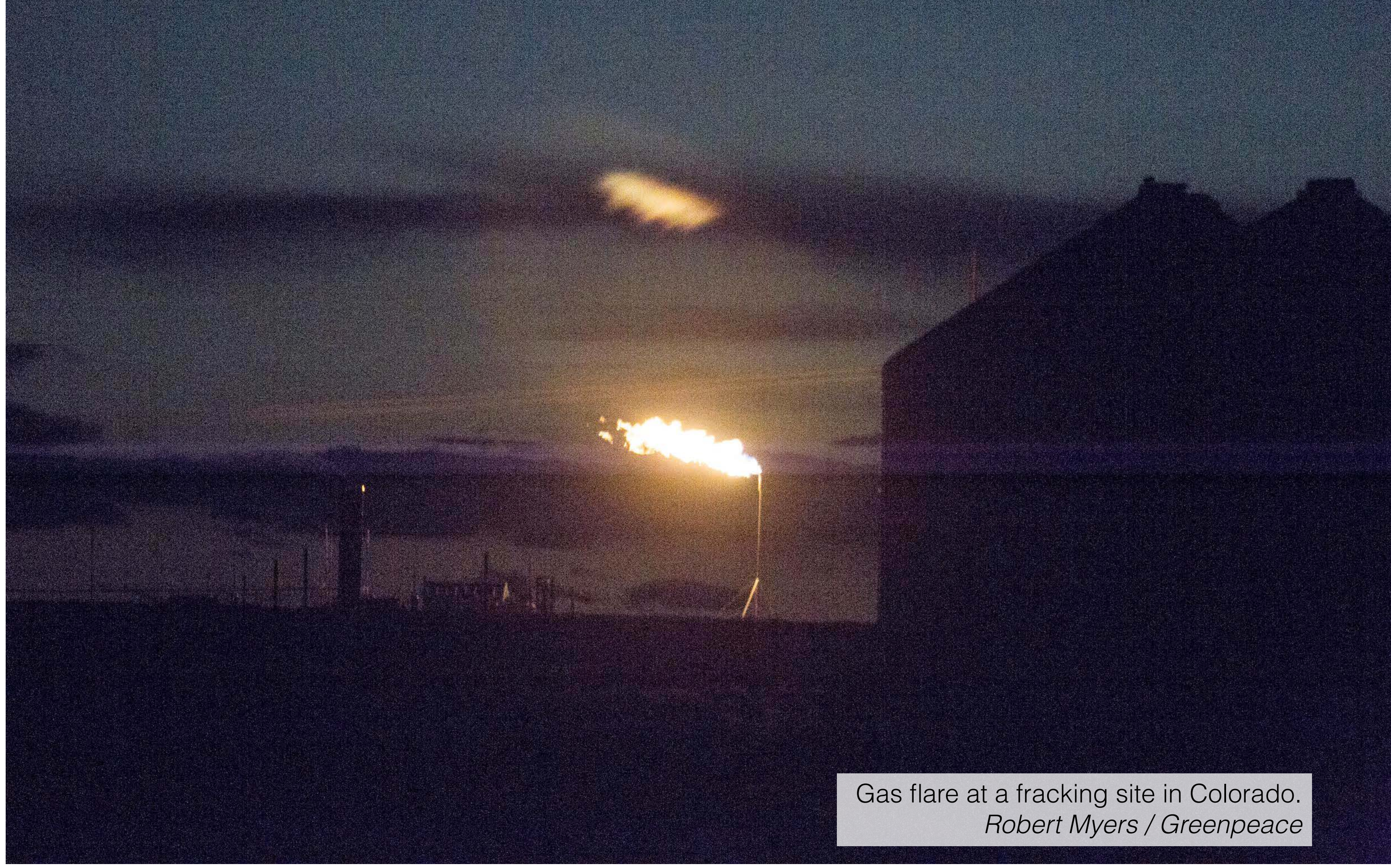
> *"Assuming truck movements are concentrated in the early years of drilling activity, this averages out at 6.1-17.1 per day over five years. Spread over their estimated 100 well pads that would add up to between 1-3 million truck movements."*

A report by AEA Technology for the European Union estimated that during the most intensive period there could be up to 250 truck movements a day to a single (10 well) drilling site. In total such a pad would require 7-11,000 truck movements, a lower estimate than the IOD which ascribes extremely high productivity to each well (so using more water).

The AEA Technology notes that truck movements could be reduced by the construction of temporary pipelines for the transportation of water. There are questions though as to whether chemicals would then need to be added to fracking fluids on site and whether such pipelines could be used for waste fluids. The construction of such pipelines would also be likely to cause disruption.

iv. Air pollution and flaring

The volume of truck traffic described is likely to increase local noise and air pollution associated with road traffic. It will also have a significant traffic impact on local roads, especially in areas where new road building is impractical or environmentally destructive, such as the Lake District.



Gas flare at a fracking site in Colorado.
Robert Myers / Greenpeace

At the exploratory stage shale gas drilling will almost certainly involve gas flaring – unless companies have plans to capture and use the gas found, which is unlikely. At the production stage flaring remains possible on an occasional basis. There is a question over whether the degree of flaring will differ between gas and oil plays – for example it will be different in primarily shale gas in Lancashire and oil drilling sites in the Weald, South East England.

Reports from the Bakken shale in the US suggest oil companies have burnt off enough gas there to power all the homes in Washington and Chicago – in gas flaring that can be seen from space. Various academic and media articles have mentioned pollution from (often diesel) fracking traffic and from site operations including flaring as a source of local air pollution.

v. Property prices

Because UK property owners do not own the oil or gas under their feet, and because the impact of fracking on property prices seems likely to be negative, property owners are unlikely to be supportive of fracking.

Evidence from the United States is mixed. However there is evidence to suggest prices fall sharply where there is a risk to water supplies from fracking or where houses are especially close to drilling.

E-serve, a leading UK chartered surveyor, has warned that prices close to fracking areas in the UK could fall in the short term, mimicking the impact of High Speed 2, the high speed rail project. Lancashire estate agents have reported sales falling through due to the possibility of fracking nearby.

8. Social and environmental risks of fracking

i. Air pollutants

Emissions of methane or volatile organic compounds (VOCs) can occur as a result of fracking. The gasses can be released through the borehole itself or through storage of flowback water at the surface.

A 2013 draft paper by Public Health England (PHE) which reviewed the literature prior to December 2012 found fracking can cause the release of volatile organic compounds (VOCs) and that

> *"a number of studies and data suggest that shale gas extraction can be a source of air pollutants such as nitrogen oxide (NOx) and particulate matter (PM) and the precursors of secondary pollutants such as ozone."*

The study found pollution can occur from direct emissions from engines powering fracking operations, emissions from venting or condensate on site and emissions from gas capture or flaring.

Whilst the study found that pollution from an individual well would be "small and intermittent" it concluded the cumulative impacts could be more significant.

According to the PHE report a study by Zielinska et al (2010) found more than 70 VOCs in the vicinity of fracking operations. The most abundant VOCs were ethane, propane, butane and pentanes with the source appearing to be leaking condensate tanks.

A study by the Arkansas Department of Environmental Quality (2011) found emissions from engines powering compressors, drilling rigs and pumps were also significant pollutants being the main sources of NOx, carbon monoxide and sulphur dioxide. The PHE report noted that the significance of emissions from drilling equipment and associated traffic was also highlighted by the AEA Technology report for the European Commission (2012).

In its environmental impact assessment for shale gas the Environment Agency identifies a high risk of VOC releases, however the EA argues that its own regulatory measures have minimised this risk.

Tanks at a fracking site in Colorado.
Robert Myers / Greenpeace

ii. Water contamination

The biggest environmental risk from shale gas extraction is pollution to water, either in the local environment in lakes and rivers or in local water drinking supplies.

According to a study by the United Nations Environment Programme (UNEP),

> *"Spills or leaks can…occur during the transport, mixing and storage of the water and flowback."*

These spills only matter because the process of fracking often involves the use of chemicals and minerals which could cause serious harm if released into the water supply or the natural environment.

iii. Fracking and water: Impacts

1) Fracking fluid

Cuadrilla has listed Polyacrylamide friction reducers (0.075%), Hydrochloric acid (0.125%) and Biocide (0.005%) as three chemicals it has used so far.

In the US the list is far longer according to a Texas University study. Many of the chemicals used in the US are toxic and the health hazards of those chemicals have been examined by academics, and found to be serious. Indeed an assessment of 353 chemicals known to be used in fracking in the US found that:

- 25% could cause cancer;
- 40 - 50% could affect the nervous, immune and cardiovascular systems;
- and more than 75% could affect the skin, eyes and respiratory system.

It is important to note that these affects would depend on human exposure at significant levels. The Environment Agency have indicated to Greenpeace that they would not allow the use of any chemicals defined as hazardous to groundwater – which means highly toxic and likely to remain in the ground unchanged for a long time. That doesn't mean, however, that toxic or dangerous chemicals cannot be used.

Friends of the Earth have calculated that fracking a shale gas well takes approximately four million gallons (approximately 15 million litres) of water. This water volume estimate is consistent with AEA Technology's study. If you assume that the chemicals are just 0.5% of the water used, then this means that each fracking operation may involve 20,000 gallons (about 75,000 litres) of chemical additives.

However it is unclear which chemicals will be used in the UK. The US EPA found that diesel fuel, which may pose some environmental and health concerns, was sometimes used in fluids for hydraulic fracturing. In documents seen by Greenpeace the Environment Agency raised particular concerns about the use of diesel, which contains potentially carcinogenic chemicals, sugesting its use may be banned in the UK.

2) Flowback fluid

In addition to the chemicals added to fracking fluid the fluid itself picks up toxins and minerals during use. Much of this remains underground but between 20-80% returns to the surface as flowback fluid.

Flowback fluid from the Lancashire shale contained, according to the EA,

> *"Notably high levels of sodium, chloride, bromide and iron, as well as higher values of lead, magnesium and zinc compared with the local mains water that is used for injecting into the shale."*

It also contains Naturally Occurring Radioactive Materials (NORM) released from the rocks. NORM is not considered dangerous at low concentrations but could be harmful to the natural environment in higher concentrations.

The nature of flowback depends on the rocks being fracked. A report by the US Geological Survey told BTEX, phenols and polycyclic aromatic hydrocarbons have been found in flowback water. The flowback fluid is normally either buried – causing seismic risks – or sent for treatment. A 2013 study by scientists at Duke University reportedly found dangerous levels of radioactivity and salinity at a shale gas waste disposal site that could contaminate drinking water.

The UNEP report states:

> *"There is a risk that fracturing the rocks might ease the migration of naturally occurring toxic substances present in the subsurface, such as mercury, lead, or arsenic."*

Substances contained in flow-back may be liberated by chemical reactions with the fracking fluid itself.

3) Drilling materials

Fracking involves the use of drilling muds and drill cuttings. An AEA Technology report for the EC warned:

> *"A well with a 1,200 metre horizontal section would give rise to approximately 47 cubic metres of mud and cuttings… drilling muds are known to contain a wide variety of chemicals that might impact drinking water resources."*

iv. Fracking and water: Risks

There are four parts of the fracking process which each pose their own risk of water contamination:

1. Risks around the transportation and mixing of the chemicals, identified by the EA amongst others.
2. Risk around the contamination of water from chemicals in the fracking fluid or methane released by the fracking process.
3. Risks of contamination from flow back fluid, either at the fracking site, during transport or at the treatment site.
4. Risks of contamination from drilling mud and drill cuttings which can release similar chemicals to those found in flow-back fluid. Drilling equipment may also be radioactive at times.

These risks are raised by a number of credible reports including the AEA Technology assessment for the EU, the AMEC report for UK Water Industry Research (UKWIR), Water UK's public statements and a 2011 report by the New York Times listing carcinogens and radioactive NORM amongst the wastes discharged into US rivers.

The Environment Agency risk assessment for shale gas identified high risks of pollution serious enough to cause a breach of an environmental standard, with an impact on the local population or surrounding environment. It identified leaking of chemicals in fracking fluid, overuse of water supplies, the leakage of chemicals during storage, transport or mixing – but said all these risks would be minimised by existing regulation.

The AEA Technology concludes that during large-scale shale gas extraction

> *"The risks of surface water and groundwater contamination during the technical hydraulic fracturing stage are considered moderate to high. The potential wearing effects of repeated fracturing on well construction components such as casings and cement are not sufficiently understood and more research is needed."*

The EA and the AEA Technology assessments give three ways in which water can be contaminated by chemicals, fracking fluid, methane, flowback fluid or drilling muds:

1) Surface water

Contamination of surface water can occur through runoff from construction activities, spills and leaks of drilling muds and/or from poorly managed wastewater or handling of chemicals including fracking and flowback fluids. The AEA Technology report for the EU notes

> *"During the drilling stage, contamination can arise as a result of a failure to maintain stormwater controls, ineffective site management, inadequate surface and subsurface containment, poor casing construction, well blowout or component failure. If engineering controls are insufficient, the risk of accidental release increases with multiple shale gas wells."*

2) Groundwater

Contamination of groundwater can be caused by pollutants (including gas) released from the well due to well integrity failure, spillage of stored wastewaters and/or chemicals, or from fracturing running through geology.

The most probable pathway for groundwater pollution is a failure in well integrity. Evidence for this risk includes Boderick et al, who note that once installed wellbore casings provide the primary line of defence against contamination of groundwater, and state that any loss of integrity from catastrophic failure of well casing to poor cement seals can lead to a contamination event.

The US EPA highlights the potential impacts on well integrity of multiple-stage fracturing processes and of repeated fracturing of a well over its lifetime. The EPA indicates that the potential effects of repeated hydraulic fracturing treatments on well construction components (e.g., casing and cement) are not well understood. The Environment Agency in their risk assessment also identified this as an area in need of research. The AEA Technology report concludes

> *"Poor well design or construction can lead to subsurface groundwater contamination arising from aquifer penetration by the well, the flow of fluids into, or from rock formations, or the migration of combustible natural gas to water supplies."*

Contamination through fractures created by fracking deep underground is widely considered the least likely pathway for water contamination from the fracking process. Recent studies[3] have suggested drilling more than 600m under the water table is unlikely to create fractures long enough to reach the water table, although a 2013 study suggested water may travel through fractures further than previously thought.

3) Long-term contamination

Long-term contamination of groundwater and natural ecosystem can be caused by fracking.

An article by ProPublica quoting US industry sources reported that as much as 85% of fracking fluid can be left underground after operations are complete. The environmental risks of this (if there are any) are not yet widely studied. A study by Durham University argued that these risks meant fracking should not take place within 600m of drinking water aquifers.

v. Evidence of water pollution from fracking

Whilst the risk of water pollution is significant and clearly demonstrable, evidence that water pollution has occurred as a result of ongoing operations – as opposed to accidents and spills – is contested. Studies suffer from a lack of "baseline" comparisons. However it is clear from the available evidence that further research is needed into whether regulations – as applied in the US – have been sufficient to mitigate the risks.

Public Health England's study noted that the Massachusetts Institute of Technology (2011) reviewed 43 incidents of environmental pollution related to natural gas operations (including shale) and found almost 50% were related to contamination of ground water as a result of drilling operations. The most common cause of such contamination appeared to be inadequate cementing or casing; the second major cause (33%) was surface spills of stored fracking fluids or flowback water.

There are a number of key studies indicating a risk that water pollution has or will occur from different locations in the US:

1) Pavillion, Wyoming

In June 2013 the only finding by U.S. regulators of water contamination from fracking was halted by the federal government and handed over to the State of Wyoming despite a finding that

> *"of synthetic chemicals, like glycols and alcohols consistent with gas production and hydraulic fracturing fluids, and benzene concentrations well above Safe Drinking Water Act standards and high methane levels."*

The final report is set to be issued in September 2014, with the fracking company concerned reportedly providing $1.5m in funding for a "state education effort." It is one of three studies into water pollution discontinued by the EPA. The study only happened after a long campaign by local residents many of whom still have drinking water which they claim they cannot drink. This study is related to fracking in areas where the shale is geologically far more shallow, and therefore poses higher risk of water contamination than is likely in the UK.

2) Dimock, Pennsylvania

The EPA has come under attack after a leaked slideshow suggested one of its scientists believed another study into water pollution in Pennsylvania should not have been stopped, after findings which may indicate leaks from fracking contaminating water. Instead it handed the investigation to another agency which, so far, appears to have made little progress. Water wells were reportedly found to contain methane and arsenic "at levels that could present a health concern" according to the leak. That study focused on the region of Dimock, included in the 'Gasland' film and the site of repeated claims and counterclaims on water pollution. Despite widespread reporting that the water was safe, ProPublica advised that EPA did not conclude that water had not been contaminated, nor did it find the methane had not come from shale gas extraction, but instead it concluded that remedial actions (including filters fitted by the company) meant water was safe to drink. The controversy started after a ProPublica investigation found methane in the water had led one woman's drinking well to blow up and a large fine was paid by the company.

3) Pennsylvania

Researchers at Duke University published their own study in June 2013. The researchers detected elevated levels of methane, ethane and propane in groundwater samples near active fracking sites. The researchers sampled well water from 141 homes in six counties. Many of the samples contained methane, but those wells within one kilometer of a gas well showed concentrations six times higher than average. Ethane in those nearby homes was 23 times above that of homes farther away. Ten homes also showed traces of propane. Researchers argued the methane isotope identified was that of gas from the Marcellus shale not naturally occurring methane from microbes. They further argued the presence of ethane and propane suggested microbes were not the cause.

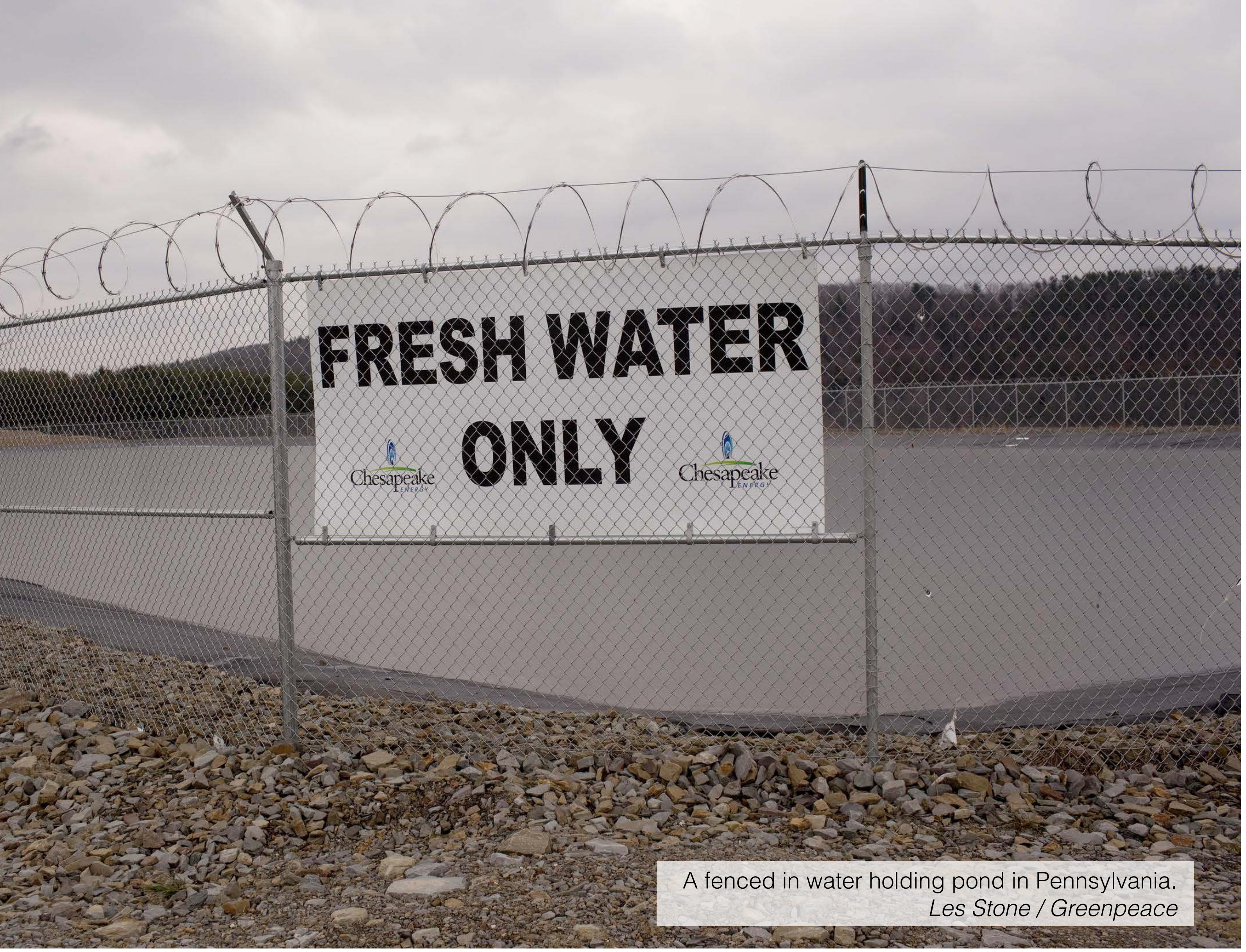
4) Texas

A peer reviewed study by the University of Texas published the in Journal of Environmental Science and Technology found elevated levels of contaminants including arsenic, barium, selenium and strontium in private water wells closest to shale gas activities in the Barnett Shale, Texas. The study team argued though that the arsenic probably didn't flow from the fracking itself but rather from the pipes of water wells disturbed by the process. The fracking or drilling nearby could dislodge rust on the inside of pipes known to contain arsenic. Researchers looked at one hundred private water wells inside and outside the active drilling area. They also compared their results to historical data. On average, researchers detected the highest levels of contaminants within 3 kilometres of natural gas wells, including several samples that had arsenic and selenium above levels considered safe by the Environmental Protection Agency. The highest concentration was 16 times the recommended level. The study does not prove that shale gas drilling caused the elevated levels but does show this is a risk factor in need of research. Possible causes include

> *"industrial accidents such as faulty gas well casings; mechanical vibrations from natural gas drilling activity disturbing particles in neglected water well equipment; or the lowering of water tables through drought or the removal of water used for the hydraulic fracturing process."*

5) Blacklick Creek Pennsylvania

A Duke University study into water downstream from a treatment plant found dangerous levels of radioactivity and salinity from fracking fluid. The study examined the water discharged from Josephine Brine Treatment Facility into Blacklick Creek, which feeds into a water source for western Pennsylvania cities, including Pittsburgh. Scientists took samples upstream and downstream from the treatment facility over a two-year period, with the last sample taken in June 2013. Elevated levels of chloride and



A fenced in water holding pond in Pennsylvania.
Les Stone / Greenpeace

bromide, combined with strontium, radium, oxygen, and hydrogen isotopic compositions, are present in the Marcellus shale wastewaters, the study found. Hundreds of disposal sites for wastewater could be similarly affected, said Professor Avner Vengosh, one of the authors of the study published in Environmental Science & Technology (a peer-reviewed journal) said,

> *"If people don't live in those places, it's not an immediate threat in terms of radioactivity. However, there's the danger of slow bio-accumulation of the radium. It will eventually end up in fish and that is a biological danger."*

The EPA continues to study water contamination in general, but findings will not be published until 2014 or later. Methane may not be considered a contaminant in water at low concentrations, so studies may find methane without finding contaminants. The EPA's study plan includes an undertaking to measure methane in surface water, groundwater and soils if potential impacts are identified. The US Water Systems Council claims that that

> *"Methane concentrations below 10 mg/L are generally considered safe. Wells with levels between 10 and 28 mg/L should be regularly monitored, and well owners may wish to consider treatment to lower the methane level."*

A study by the Pennsylvania Environmental Protection Agency found evidence of leakage of gas from more than 6% of new gas wells due to cement failure:

> *"Pennsylvania's Department of Environmental Protection has tracked gas leaking from wells across the state. They found 6.2 percent of new gas wells were leaking in 2010, 6.2 percent in 2011 and 7.2 percent so far in 2012."*

The UK EA argues that because fracking fluid should not contain highly hazardous chemicals and because regulatory controls will be applied to fracking operations to prevent leakage the risk of groundwater contamination is very low.

Greenpeace argues that the evidence would suggest fracking poses risks of groundwater and surface water contamination over the longer term.

vi. Accidents and spills

On the basis of documented experience so far, the greatest risk posed by shale gas drilling appears to come from accidents and spills during the fracking process or the transportation of water and chemicals. In a shale gas environmental impact assessment the Environment Agency said:

> *"Our experience of regulating industrial sites is that accidents can and do happen. However there are few reports of significant pollution incidents from this source in the USA."*

The agency further argues that the impact of any spill would be reduced because of regulatory measures in place to ensure sites are effectively sealed from the natural environment.

However as Alberta's Energy Resources Conservation Board spokesman Darin Barter warned

> *"There is no amount of regulation that can overcome human error."*

This was in response to an incident in which workers from Crew Energy and GasFrac accidentally fracked directly into an underground water table in Grande Prairie, Alberta in September 2011. This resulted in 42 cubic metres of unrecoverable propane gel, as well as toxic fracking fluid chemicals, being injected into an aquifer about 136 metres below ground. The firm is one of a number who have been implicated in spills and accidents impacting on water and the local environment, as reported by Texas University.

The Times reports that two senior US politicians have urged Congress to investigate spills from fracking sites. Members of Congress Jared Polis and Peter DeFazio wrote to the House Resources Committee with their concerns that

> *"Despite industry efforts to minimize contamination events, there have still been well documented instances of leaking and spills from tanks, wells and pipelines."*

Public Health England's 2013 study noted that the US EPA (2012) reported the main cause of incidents to be surface spills of fracking fluids or flowback waters, or blowouts giving rise to uncontrolled fluid releases.

This timeline shows the accidents and spills that have occurred in the US between April 2009 and September 2013.

2009 | 2010 | 2011 | 2012 | 2013

In April 2009 in Foster Township, PA, drilling activities impacted at least seven drinking water supplies. According to a report by the Tyndall Centre

> *"Stray gas became evident in wells and residents complained. Two of the affected water supplies contained methane and five had iron and manganese above established drinking water standards. After investigating, the Pennsylvania Department for Environmental Protection found that the stray gas occurrence is a result of 26 recently drilled wells, four of which had excessive pressure at the surface casing seat and others that had no cement returns."*

In April 2009 in Caddo Parish, Louisiana seventeen cattle were found dead near a drilling site. Louisiana regulators concluded that fracking fluid leaked from the well pad and ran into an adjacent pasture. The private companies involved were reportedly fined $22,000.

In September 2009, residents of Dimock, Pennsylvania experienced three spills of fracking fluid totaling more than 8000 gallons. The spills entered a nearby creek and the operators were fined $56,650 by Pennsylvania regulators.

In October 2009 in Hopewell Township, Pennsylvania, a spill of fracking fluid into a water body resulted the death of fish. Pennsylvania regulators fined the company responsible $141,175.

In June 2010 EOG Resources had a blowout in Pennsylvania well that reportedly discharged 35,000 gallons of fracking fluid into a state forest. The firm said in a statement that "at this time, EOG believes that any impact to area streams and springs and to the environment is minimal."

In July 2013, XTO Energy – a division of ExxonMobil – reached a settlement with US regulators to pay $100,000 and spend millions to upgrade existing facilities after a 2010 spill of toxic wastewater in Pennsylvania. They are now being sued by Federal government. The U.S. Department of Justice claims XTO Energy allowed flowback fluid and wastewater byproduct to reach water supplies. The complaint from the Department says that "flowback fluid and produced fluid contain brine, proppant, hydraulic fracturing chemicals, dissolved solids, heavy metals and radionuclides."

In September 2013, more than 40,000 gallons of oil and an unknown amount of waste drilling water leaked from sites in Colorado last month because of floods that killed eight people and damaged nearly 2,000 homes. The incident meant a visit to Noble Energy's site by the UK Minister for Energy and Climate Change, Greg Barker, had to be rescheduled.

The State of New Mexico has reportedly documented 700 cases of water contamination from waste pits linked to the oil and gas industry.

A map of fracking accidents has been made by Earth Justice, however the data in the map has not been verified by Greenpeace.

vii. Naturally Occurring Radioactive Material

As noted, hydraulic fracturing releases naturally occurring radioactive wastes into the fracking fluid. Although the waste is very low-level, the volumes of fluid involved and the need to transport and dispose of the waste opens up environmental risks.

A 2011 report by the New York Times found that most US waste processing facilities

> *"Cannot remove enough of the radioactive material to meet federal drinking-water standards before discharging the wastewater into rivers, sometimes just miles upstream from drinking-water intake plants."*

A 2013 Duke University study into water downstream from a flow-back fluid treatment plant found elevated levels of radioactivity and salinity from fracking fluid, which one of the authors said could become a "biological danger" through bioaccumulation.

In its Environmental Risk Assessment for Shale the Environment Agency lists exposure to NORM as a possible risk in shale gas exploration, and requires shale gas drillers to obtain a permit for the extraction and handling of radioactive materials. Radium 226 was the highest naturally occurring radioactive material (NORM) found in the flow back water from the Bowland shale measuring between 14 and 90 becquerel per litre according to an analysis by the EA in December 2011. According to the EPA,

> *"Both internal and external exposure to gamma radiation is harmful. Gamma rays can penetrate the body, so gamma emitters like radium can result in exposures even when the source is a distance away."*

A report by AEA Technology for the European Commission on the possible environmental risks of shale gas drilling in the EU noted that

> *"The substances of potential concern comprise naturally occurring substances such as heavy metals, together with natural gas, naturally occurring radioactive material (NORM), and technologically enhanced NORM (TENORM) from drilling operations."*

In April 2013 a truck carrying drill cuttings from a fracking pad in the Marcellus Shale was rejected by a Pennsylvania landfill site because it set off a radiation alarm. The truck was emitting gamma radiation from radium 226 at almost ten times the level permitted at the landfill. While radium 226 occurs naturally in the Marcellus Shale (as well as the Bowland shale in the UK), Pennsylvania's Department of Environmental Protection has launched a year-long study into radiation contamination associated with fracking wells. It will also be looking into the radioactivity levels in pipes and well casings, storage tanks, treatment systems, and trucks.

In June 2013 FreshWater Accountability Project Ohio issued a report criticising radioactive waste disposal from fracking in Ohio, claiming that the waste can make its way into municipal landfills. The report, co-authored by Marvin Resnikoff, a physicist at the University of Michigan and senior associate at Radioactive Waste Management Associates, states:

> *"Drilling contamination is entering the environment in areas directly connected to the drilling site through spills, too. In the past three years, at least 16 wells whose records showed high levels of radioactivity in their wastewater also reported spills, leaks or failures of pits where hydro-fracking fluid or waste is stored, according to State records."*

The report also found that in many instances truck transportation of radioactive waste in Ohio violates federal standards, which includes truck tank design, minimum insurance requirements and proper signage indicating the load is radioactive.

viii. Health risks

The risk of air and water contamination from chemicals and toxic substances related to fracking along with anecdotal reports of health impacts has raised legitimate health concerns. Many of the risks discussed above – such as accidental leaks of fluid into water supplies or evidence of contamination of treated water – could lead to health risks due to chemicals released from the fracking process or secondary impacts of drilling, e.g. road pollution.

Methane itself is not always considered harmful at very low levels but at high levels can cause asphyxiation or even explosions e.g. if methane leaks into a house, as may occur if it is present in the water supply. Emissions of volatile organic compounds (VOCs) linked to shale gas drilling due to problems with well integrity could have a significant impact on local air quality and may pose a risk to public health.

In a shale gas risk assessment the Environment Agency identified a high risks of fugitive emissions of methane and volatile organic compounds from the borehole, from methane storage and from treatment of fracking fluids, in absence of regulatory controls. The controls, it concluded, would reduce this risk to low.

The agency quoted two US studies:

> *"Groat and Grimshaw (2012) indicated that a significant percentage of offshore wells have shown some degree of well integrity issues. Considine et al. (2012) reported similar evidence for onshore shale gas wells in the USA."*

The agency warned of "respiratory illnesses caused by VOCs" along with "asphyxiation, explosion and fire risks from methane." However the agency argued that measures implemented by it and the UK Health and Safety executive would reduce these risks to 'low'.

There have been numerous complaints about health impacts as a result of fracking operations. The Pennsylvania Alliance for Clean Water and Air has listed those who claim to have been harmed by fracking. No peer reviewed study has so far shown a clear health impact (as opposed to risk) from fracking operations on humans, neither have studies shown that the risk is absent, suggesting a need for further research in this field where the current evidence is limited.

The situation is probably not helped by the repeated imposition of gagging orders on those who complain of health impacts – often as part of high value settlements. In 2013 it was revealed that two children, aged seven and ten, from Pennsylvania were subject to lifetime gagging orders as a result of a $750,000 settlement between their parents and a leading oil and gas company. The Hallowich family had earlier accused oil and gas companies of destroying their ten acre farm in Mount Pleasant, Pennsylvania and putting their children's health in danger.

In the same year Mother Jones reported that under a new law, doctors in Pennsylvania can access information about chemicals used in natural gas extraction – but companies will be able to prevent them sharing it with their patients. The law has led doctors in the region to threaten legal action, suggesting it forces them to compromise medical ethics.

Two US studies have indicated contamination of air quality around shale gas drilling sites – though they have not shown a direct link to drilling. A 2012 study by Colborn et al indicated high levels of non-methane hydrocarbons (NMHCs) around the drilling phase. Of over 50 non-methane hydrocarbons near shale gas wells, 44 have health impacts including 35 which affect the brain and nervous system. However, the study did not show that residents had suffered adverse health impacts.

A separate study from the Colorado School of Public Health reported in Businessweek found that air pollution caused by fracking may contribute to acute and chronic health problems for those living near natural gas drilling sites. The study argued higher levels of benzene could lead to an increased health risk – though again it did not prove the air pollution originated from fracking operations. Benzene is linked to the use of diesel in fracking operations. The authors noted that the risks were at a very low level (around 1 in 100,000 cancer risk for those less than half a mile from the well) and therefore called for further study of the health impacts of shale gas extraction before drawing conclusions. Benzene is likely to be banned in the UK.

A 2013 draft paper by Public Health England (PHE) described the key finding of the Colorado study (McKenzie L.M et al 2012 and Colorado School of Public Health 2011) as showing that

> *"calculated potential for risks for sub-chronic non-cancer endpoints (20 months exposure) were elevated for those residents within half a mile of the gas wells during well completion."*

However it suggested the application of these results to other developments in the UK would be very difficult.

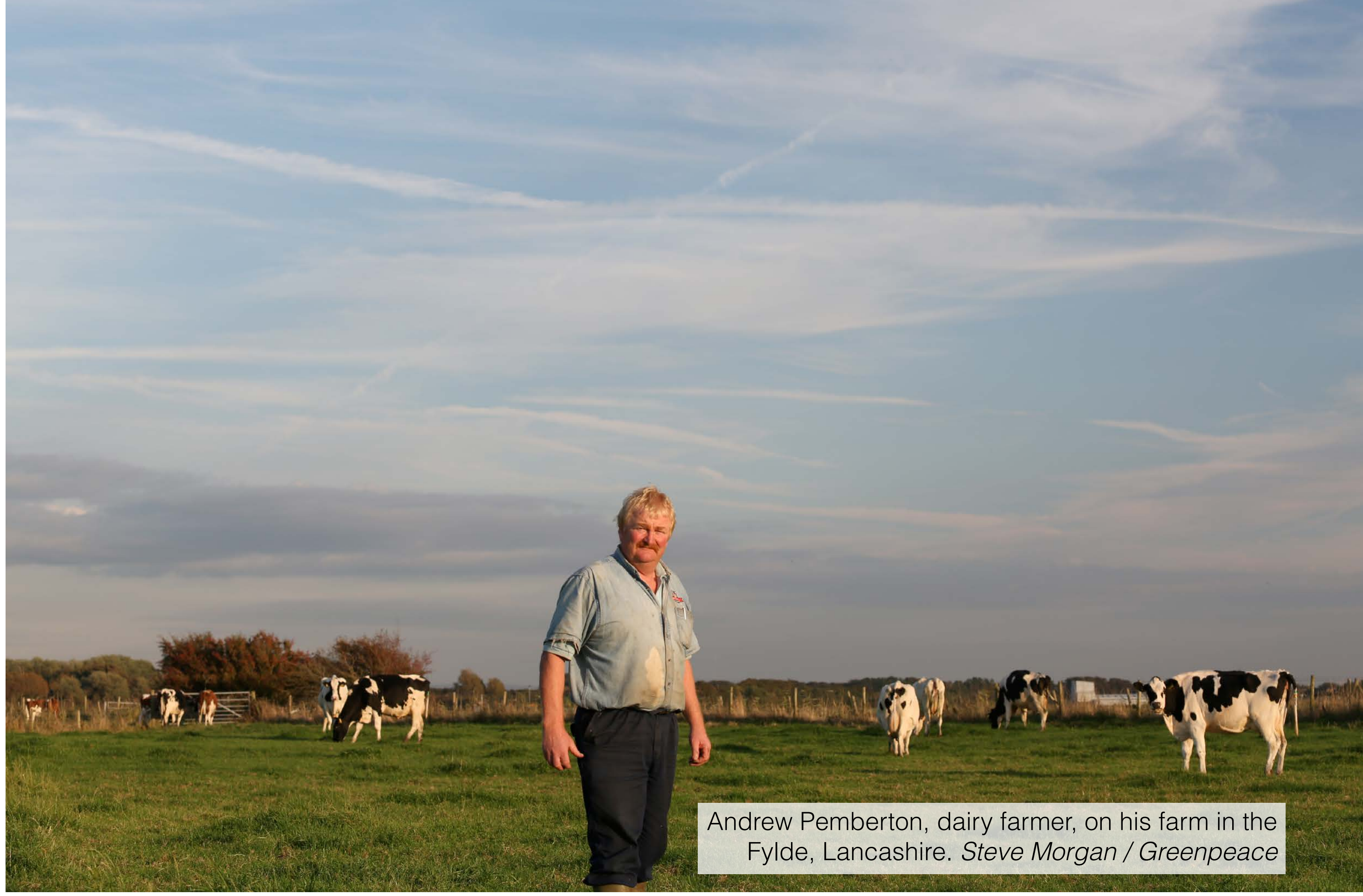
In its review of the literature up until December 2012 PHE concluded that the available evidence suggested air quality could be impacted by fracking through the release of VOCs and pollutants including nitrogen oxide, sulphur dioxide and ozone.

It argued that whilst the individual impact of any one well would be small

> *"the cumulative impact of a number of well pads may be locally and regionally quite significant."*

PHE also examined the risks from water contamination and radiation concluding, in both cases, that the risks were relatively low to the wider population – with proper regulation. However the paper argued that the 1% of the UK population which does not get mains treated water would be "particularly vulnerable" to any water contamination occurring from problems with well casings or spills.

It noted that surface or subsurface blowouts involving fracking fluid have caused contamination of surrounding land and groundwater. In its analysis PHE concluded that the "the risks to public health from exposure to the emissions associated with shale gas extraction are low, if the operations are properly run and regulated," arguing that health risks typically arose from poor industry practice or poor regulation.



Andrew Pemberton, dairy farmer, on his farm in the Fylde, Lancashire. *Steve Morgan / Greenpeace*

However, the draft study argued that

> *"comprehensive air monitoring [on a regional basis] and associated assessments of health risks will be required in the UK to inform regulation at each phase of operation."*

A 2012 Cornell peer-reviewed study (Bamberger et al) warned that livestock near fracking sites were falling ill and experienced neurological, reproductive and acute gastrointestinal problems after being exposed – either accidentally or incidentally – to fracking chemicals in the water or air, often due to leaks and spills. The authors - who looked at a leak causing the death of 17 cows as part of their study – accept the research could not prove a direct link to fracking – but argued this was largely due to non-disclosure by the industry arguing:

> *"The findings illustrate which aspects of the drilling process may lead to health problems and suggest modifications that would lessen but not eliminate impacts. Complete evidence regarding health impacts of gas drilling cannot be obtained due to incomplete testing and disclosure of chemicals, and nondisclosure agreements."*

One author of the study, Professor Oswald, has argued the UK should suspend fracking until more research is carried out, telling The Ecologist:

> *"[British] farmers living in intensively drilled areas should be very concerned about potential exposures of their crops and herds to shale-gas contaminants in the water, air and soil."*

A number of other studies have also taken place, though their results are less clear. In 2011 the New York Times reported a 25% increase in asthma rates in parts of Texas heavily impacted by drilling, however the article did not show that the increase was linked to fracking. US biologist Sandra Seinberger has provoked controversy by suggesting her students publicly discuss a finding that the health of newborns could be affected by the proximity of their mothers to fracking wells in Pennsylvania before the paper was peer reviewed. Similarly the 'Gasland' filmmaker Josh Fox quoted reports of breast cancer clusters linked to drilling in the sequel film 'The sky is pink'. Neither claim is peer reviewed.

Another unpublished study carried out by a Colorado doctor compared blood samples from eleven patients in Erie and compared those to samples taken from ten controlled patients in Carbondale. Dr. Hughes said:

> *"We basically found a high level of ethyl benzene in the patients [from Erie.]"*

But a separate study commissioned by the town of Erie and conducted by the environmental firm, Pinyon Environmental of Lakewood, measured levels of emissions in summer 2012 near wellheads in Erie. It found "concentrations of various compounds (ethane, propane, butane and benzene) comparatively low and not likely to raise significant health issues."

Leaked documents from an investigation by the New York Health Department suggest that 'mitigation measures' would ensure fracking was safe. However the report was criticised by campaigners in the state. The health concerns have led some US states to carry out health impact assessments (HIAs) ahead of allowing shale gas operations. In 2009, the Colorado School of Public Health was contracted by Garfield County to conduct a HIA of 200 proposed natural gas wells in the community of Battlement Mesa, and reported:

> *"The team found that the natural gas project could contribute to health effects such as headaches, upper respiratory illness, nausea and nosebleeds and a possible small increase in lifetime cancer risks as a result of air emissions."*

The study is not an investigation of observed impacts, but was designed to highlight potential risks from the extraction process. The author said:

> *"The whole goal is to provide recommendations to reduce impacts before you start. The assessment is a means to an end. It's a critical public health tool."*

Health investigations are continuing in the US. In 2013 Geisinger, a major healthcare provider in Pennslvania, launched a new study looking to analyse relevent health data. Study author Dr. Carey states:

> *"We want to do this in a scientifically rigorous and unbiased way. We're not going into this with any preconceived notions. To determine the long term outcomes, we need solid data that can be used to guide rational policies, propose mitigations where they are needed, and reduce exposures."*

9. Earthquakes

There is evidence that processes linked to the shale oil and gas can cause small earthquakes, which may affect the integrity of drilling equipment.

There is no evidence that fracking alone can cause earthquakes with significant surface impacts. However a study by Columbia University found significant increases in seismicity (with significant surface impacts) linked to waste water injection from fracking sites triggered by earthquakes hundreds of miles away. The Royal Society report on shale gas notes that:

> *"On 1st April 2011, the Blackpool area experienced a seismic event of magnitude 2.3 ML shortly after Cuadrilla's Preese Hall well in the Bowland Shale was hydraulically fractured."*

In another seismic event of magnitude 1.5 ML the Royal Society observed the earthquake led to deformation of the well-casing, but because of the depth and the fact the casing was already perforated it was not serious in this case. The Royal society notes that:

> *"Reports attribute the two seismic events to Cuadrilla's fracturing operations. The most likely cause of the events was the transmission of injected fluid to a nearby (but previously unidentified) pre-stressed fault, reducing the effective stress to the point where the fault slipped and released its stored energy."*

The report concludes:

> *"Bedding planes in the Bowland Shale are weak enough to have slipped and provided a conduit for fluid to flow out of the well and into the fault zone."*

Johnny Imber, a Geologist at Durham University, confirmed with Greenpeace Energydesk that in his view this causal mechanism is common to most UK shale gas areas. Green et al concluded that the damage done to the well integrity in this case was sufficiently deep that it would not cause problems further up, and closer to the water table, not least as it damaged a bit of well that already had pores in it for fracking. However the Royal Society recommends that DECC should consider the conditions under which repeat pressure tests and/or cement bond logs (CBLs) would be required to provide evidence about whether well integrity had been compromised following unexpected levels of induced seismicity.

The Columbia study was released after the Royal Society report. Its authors concluded that wastewater injection could put stresses on faults which are then triggered by large earthquakes further away – in the case of the US as far away as Chile. Amongst the tremors researchers examined was a magnitude 5.7 quake near the US town of Prague, Oklahoma, which was preceded by a 5.0 shock and followed by thousands of aftershocks. It said the quake had been preceded by an increase in the pressure of wastewater injection in an area known to have a fault line and a major quake in Chile. But the authors noted that

> *"Hydrofracking itself is not implicated in significant earthquakes; the amount of water used is usually not enough to produce substantial shaking."*

The Royal Society also notes the increased seismic risk from water disposal.

In its coverage of the story the BBC observed that wastewater injection is not currently legal in the EU, however the Royal Society report suggests disposal would be possible with a permit. The Environment Agency confirmed this, but said the issue was complicated by the mining waste directive which specifies that only clean water could be injected.

The study therefore does not show a significant risk of UK fracking leading to significant surface quakes. However because UK fracking is geologically different to the US – it is deeper, there are more faults and there is a suggested mechanism for water to travel to those faults – it does suggest the need for further research and monitoring into this area. In a report last year the US National Academy called for further research into induced seismic events.

10. Vulnerable habitats & bird life

Licences for oil or gas drilling have been or could be issued across 64% of the UK. Outside urban areas drilling is likely to take place either in or near sensitive areas such as nature reserves, sites of special scientific interest or RSPB reserves. The main threat to vulnerable natural habitats comes from the risk of spillages or other industrial accidents involving fracking fluids, chemicals and muds either on site or in transport. However noise and sound pollution – including vibrations – could also pose a threat to sensitive bird life.

Drilling by Cuadrilla in Lancashire has been delayed and cancelled due to the presence of birds wintering near the Flyde Peninsula.

In Poland residents of of Zurawlow set up a blockade which successfully prevented Chevron from launching operations on a site earmarked for drilling. They referred to a law prohibiting any kind of work that would threaten birds' habitats during breeding season.

The UNEP report details the impacts of nonylphenol – a chemical commonly found in fracking fluid – on fish. It finds that nonylphenol, which mimics estrogen,

> *"can cause feminisation of fish, even at concentrations not detected by normal monitoring of the fluid."*

11. Regulation of risks

The regulation of environmental risks lies mainly with the Environment Agency, though local mineral authorities are responsible for taking into account environmentally sensitive areas and the health and safety executive is responsible for regulations around well safety and, to an extent, well integrity. DECC regulates seismicity.

The Environment Agency in its risk assessment argues that almost all of the risks of air and water contamination and any associated risk to health was reduced to 'low' due to the regulatory steps being put in place by it and the government.

However, as the Gulf of Mexico oil spill has shown, regulating away accidents, spills and failures has proven hard especially because fracking involves thousands of wells and huge volumes of water and chemicals. The concerns are particularly acute because so much of the monitoring is left to the companies themselves and (perhaps not coincidentally) the regulators of shale gas drilling are themselves under budgetary pressures as their core budgets are cut.

i. Monitoring

Independent monitoring is limited or nonexistent. The minerals authority – which is not primarily responsible for environmental issues – may only charge for eight site visits for monitoring in each year. The Environment Agency's technical guidance (along with the DECC guidance on seismic activity) suggests that firms will be responsible for self-monitoring of the following areas: fracking fluids, fracking well fluids, wellbore integrity, potential spillages and methane leakage. Any monitoring by the EA will be limited to occasional and mostly limited to early stages. Indeed the EA's technical guidance advises on monitoring for spillages states that:

> *"You don't need a permit to discharge clean surface water run-off (for example from a roof, road, pathway or clean hardstanding area) to a watercourse. The run-off should be managed so as to ensure it stays clean and uncontaminated. An appropriate monitoring regime should be included. If surface water run-off does become contaminated, you should inform us."*

A recent report by Ends suggested that cuts to the Environment Agency budget would further weaken its monitoring powers. A source quoted by Ends said:

> *"We've already changed our ways of working so we regulate industry in a much more risk-based way and we rely on operators to self-report problems. We'll do a lot more of that I guess, but how can you guarantee businesses are self-reporting properly if you don't have the staff to check the reports?"*

A draft report by Public Health England xalled for

> *"effective environmental monitoring in the vicinity of shale gas extraction throughout the lifetime of development, production and post-production."*

The report focused on the need to monitor air, as well as water, in the region around shale gas drilling and suggested that health impact assessments (HIAs) be carried out prior to large-scale commercial drilling.

Transport of fracking fluids, drilling muds and chemicals to and from the well site will be subject to waste permits and to conditions in planning consent - but will again not be independently monitored. DECC guidance suggests that seismic activity will, initially, be independently monitored but that this monitoring regime will change during the production state. DECC states that the content of fracking fluids must be made public – unless that content is 'commercially sensitive'. There does not appear to be any obligation to disclose the contents of drilling muds or flow-back fluids. Further DECC's guidance states:

> *"There is no reason to expect any impacts on agriculture, and no plausible mechanism for such an impact has been proposed."*

Therefore no monitoring of nearby agricultural land will take place.

The transportation of naturally occurring radioactive waste may not require a permit. Tony Grayling, head of Climate Change and Communities at the EA said:

> *"Traffic movements are a matter for the local planning authority."*

According to the 2011 Exemption Guidance,

> *"All premises that store radioactive material or radioactive waste 'in transit' are exempt from the requirement to have a permit for that material or waste."*

Overall a lack of independent monitoring places significant emphasis on companies alone to manage risk. The available evidence from the United States presents a mixed picture of their ability to do so especially when operating in a new geological and environmental context.

ii. Long-term monitoring

In documents seen by Greenpeace the Environment Agency raises concerns about chemicals left in formations after wells are capped and abandoned, however it is unclear where the responsibility lies for long-term monitoring of these formations. This is especially the case for exploratory drilling.

iii. Planning

In its report on shale gas the Royal Society suggested that every shale gas operation should have a mandatory environmental risk assessment across the entire lifecycle of the operation. However planning guidance issued by the Department for Communities and Local Government (DCLG) suggests that any exploratory drilling where the footprint is less than 0.5 acres would not be eligible for an environmental impact assessment (under schedule 2 of the town and country planning act) unless it was in a 'sensitive area'.

iv. Oil

High volume fracking for oil – as opposed to gas – doesn't seem to be considered in most of the existing regulations. This means that the chemicals associated with shale oil extraction (drilling muds, fracking fluids etc) and the potential transport of far larger quantities of oil than have previously been found onshore in the UK has not been considered.

Endnotes

All references are hyperlinked.

1. Provisional figures, Broderick & Anderson, Tyndall Centre, Manchester University

2. Provisional figures, Broderick & Anderson, Tyndall Centre, Manchester University, and figures from 3rd Progress Report Ch1 supplementary materials (2011). The full range of estimates is 52% to 480% (lowest BGS + Interim pathway + 10% recovery, to highest BGS + Intended Pathway + 30% recovery).

3. Davies et al., 2012; Fisher and Warpinski 2012

"There is no amount of regulation that can overcome human error."

- Darin Barter, Alberta Energy Resources Conservation Board