

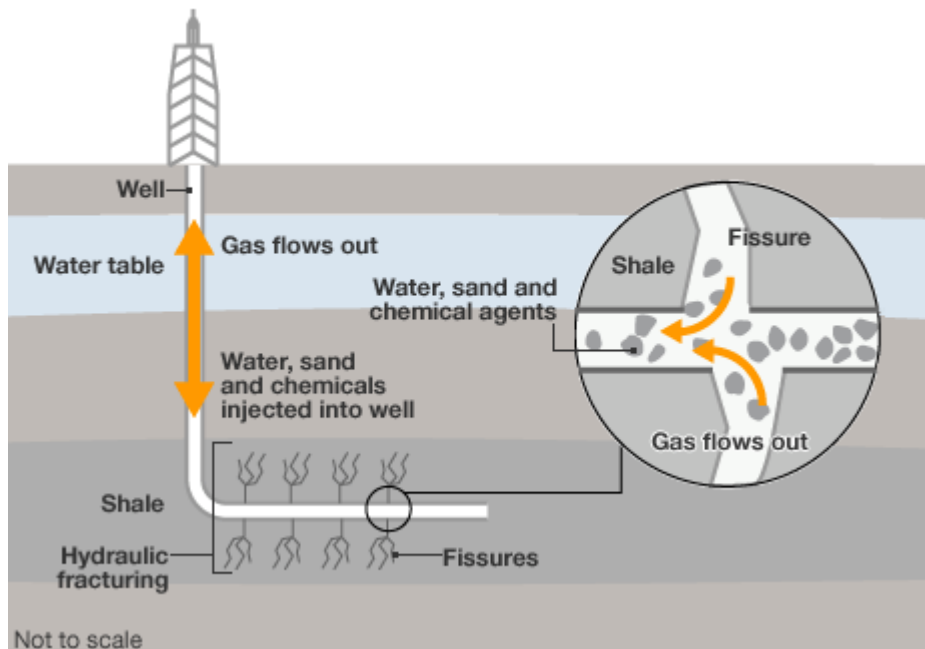
Fracking - Good or Bad?

RAWB, Last Update 4/8/14 (new part shaded blue)

What is fracking?

If you drill into geological strata containing gas or oil you do not necessarily get a lot of the hydrocarbon flowing out of the top of the hole. This will only happen if the geological strata are sufficiently porous to permit the fluid to flow through it - and thence into your bore hole. Often the strata are sufficiently porous to support flow at a commercially viable rate and this is the basis of conventional oil and gas wells. However, if the strata are not sufficiently porous then they can be made so by fracturing. This can be accomplished by injecting fluid (usually predominantly water) at very high pressure (~9000 psi). The resulting hydraulic fracturing (=fracking) renders the strata porous and can produce a profitable flow of gas or oil.

Shale gas extraction



Are explosives used in fracking?

Yes.

Once a well has been drilled and cased, explosive charges are fired to perforate holes along the bore hole at selected intervals within the shale formation. Fracturing fluids, consisting of water, sand ('proppant') and chemicals, are pumped under high pressure into the well. The injection pressure generates stresses in the shale that exceed its strength, opening up existing fractures or creating new ones. The fractures extend a few hundred metres into the rock and the newly created fractures are propped open by the sand.

Is there anything else novel about fracking technology?

Yes.

Shale-strata fracking wells consist of the usual vertical bore hole, but to a greater depth than conventional wells (typically a mile or more). The unique requirement, however, is that the drilling be able to turn to the horizontal - perhaps for several miles. It is the horizontal part, lying entirely within the shale strata, which provides the gas or oil.

Just how widespread is fracking in the USA?

Hugely!

In Colorado alone there are ~50,000 shale-strata fracking wells.

In the USA as a whole it has been estimated that ~1 million wells have been fracked since 1940, including those tapping the shallower limestone/sandstone strata. There are ~500,000 active wells of all types in the US at present.

Is fracking new to the UK?

No.

Hydraulic fracturing has been common in the UK's North Sea oil and gas fields since the late 1970s (see Detlef Mader, 1989, [*Hydraulic Proppant Fracturing and Gravel Packing*, Elsevier](#), p.174). Moreover, fracking has also been used in ~200 British *inland* sites since the 1980s (see the review by the Royal Society, [Shale gas extraction in the UK](#), June 2012, a copy of which can also be obtained from my web site). This includes the Wytch Farm field in Dorset which produces the majority of UK onshore oil and is Europe's largest onshore oil field. Although widespread use of fracking has recently become associated with the USA, in fact it has been used throughout Western Europe on inland sites since the 1980s.

So why is fracking suddenly in the news?

In common with many subjects made topical by the media, the label is misleading. The real issue is not fracking *per se*: it is hydrocarbon extraction from the unusually deep shale strata that is the issue. For this it happens that fracking is invariably required. But fracking itself is not new.

However, inland wells have been a relatively minor source of oil and gas in the UK to-date, so we have little experience of the disruption which very large scale inland extractions might cause.

If fracking has long been accepted for shallower wells, why should there be an issue now for deeper wells?

Good question. Detractors appear to be wilfully ignoring this experience. But practical, full scale engineering experience should be given far greater weight in judging the issue than theorising or scaremongering.

Will fracking cause gas to come out of my water tap?

No.

One of the most iconic symbols of the fracking debate is the video of a man setting his tap water on fire in the infamous 2010 anti-fracking documentary *Gasland*, see http://www.youtube.com/watch?v=XQcIAhG49y8&list=TLtMBpEIUI_1Q. The same footage has been shown on UK TV. In both cases the use of this footage in an article

about fracking carries the deliberate implication that fracking, and specifically fracking for shale gas extraction, was to blame. But no evidence to this effect was presented. Viewers in the UK will mostly be used to their water being provided via extensive piping systems from a reservoir, often many tens of miles from their home. They may not immediately appreciate that the footage in question, taken in the town of Dimock, Pennsylvania, related to water from a domestic well. In this area it is usual for property owners to drill for their own water on their own property. *Gasland* did not seem to think it necessary to enlighten the viewer as to this fact. However, this is all you need to know to begin to suspect that the source of the unwanted methane is far more likely to be shortcomings in the householder's own water well than anything to do with fracking. This suspicion is consolidated by interviews with other residents of the area who have endless stories of natural (biogenic) methane coming out of personal water wells going back 70 years. *Gasland* has been comprehensively trashed by a more recent documentary, *FrackNation*,¹ see <http://www.youtube.com/watch?v=g--2IB-3wCw>. If the anti-fracking lobby has a case it is not best served by this sort of sensationalist footage which turns out to be entirely spurious.

Of course, since gas extraction involves gas flowing up long drilled holes, it is not impossible that the gas might go where it was not intended. All engineering is fallible. So even for Dimock it is not impossible that poor shale-well casing (a relatively common occurrence) might be implicated in some instances of methane-in-water (though not in all cases since the phenomenon has been around longer than fracking). However, there appears to be no reason to regard deep shale gas extraction via fracking to be any different from other gas wells in this respect. In both cases it is a matter of sound engineering practices, particularly in regard to the integrity of the concrete well casing.

Will fracking cause earthquakes? (Original August 2013 text)

What do you mean by "an earthquake"? A lorry driving past your house may cause it to shake, perhaps up to Richter scale 3 (ML).

On 1st April 2011, the Blackpool area in north England experienced seismicity of magnitude 2.3 ML shortly after Cuadrilla Ltd hydraulically fractured a well at its Preese Hall site. Seismicity of magnitude 1.5 ML occurred on 27th May 2011 following renewed fracturing of the same well. As a result, hydraulic fracturing was suspended across the whole of the UK for ~18 months whilst reviews were carried out. Cuadrilla itself sponsored the first review, *Geomechanical Study of Bowland Shale Seismicity by Dr. C.J. de Pater and Dr. S. Baisch: Synthesis Report*, 2 November 2011, a copy of which can be found on my web site. This synthesis report utilises independent technical reports prepared by Seismik (lead investigator Dr. Leo Eisner), Q-con (lead investigator Dr. Stefan Baisch), Geosphere (Dr. Tim Harper), StrataGen (lead investigator Dr. C.J. de Pater) and Baker-GMI (lead investigator R. Guises). Amongst other things the review concluded that 3 ML events would be the worst case for fracking and associated well extraction activities. The same upper bound was found by Green *et al*².

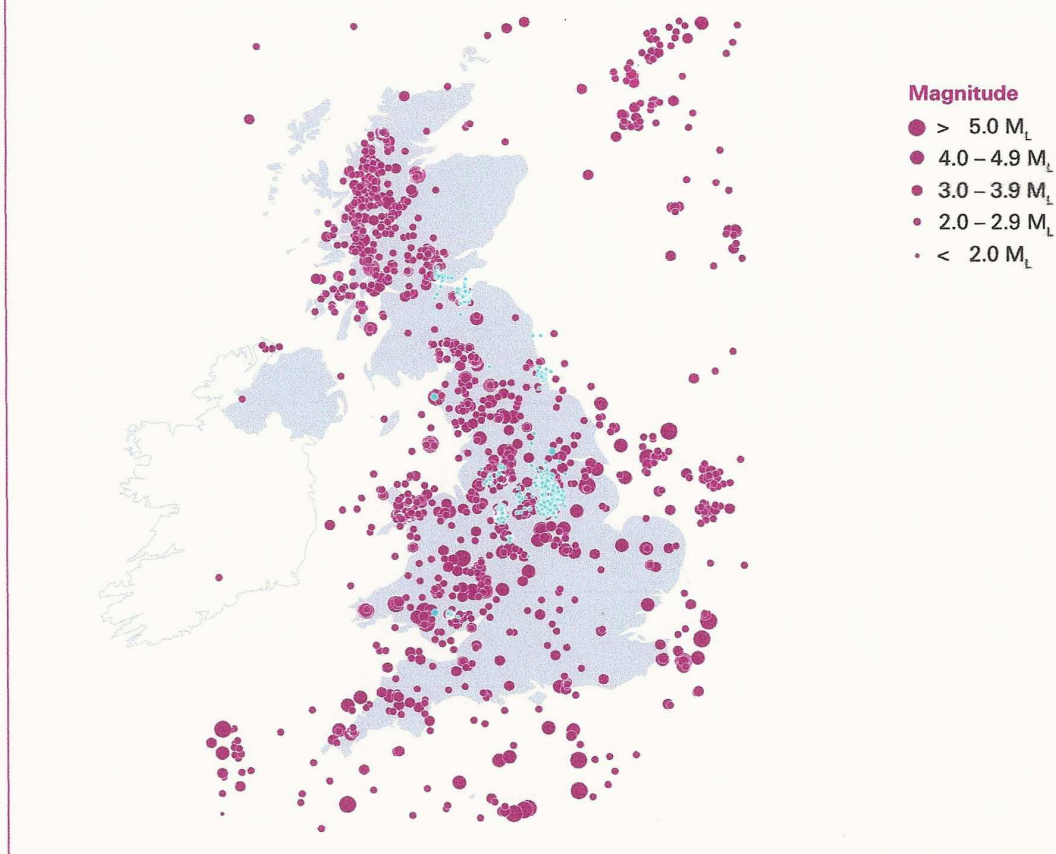
¹ I recommend you view this. The suggestion that the anti-fracking lobby might be funded by the Russians is amusing, though I'm not aware of any actual evidence to this effect.

² Green et al (2012), Preese Hall shale gas fracturing: review and recommendations for induced seismic mitigation, Department of Energy and Climate Change: London.
<http://og.decc.gov.uk/assets/og/ep/onshore/5075-preese-hall-shale-gas-fracturing-review.pdf>.

To put this in context, the UK experiences seismicity of magnitude 5 M_L (felt by everyone nearby) about every twenty years, and of magnitude 4 M_L (felt by many people) every three to four years. The UK has lived with seismicity induced by coal mining activities or the settlement of abandoned mines for a long time. British Geological Survey records indicate that coal mining-related seismicity is generally of smaller magnitude than natural seismicity and no larger than 4 M_L . The events at Preese Hall, in contrast, were of a level comparable with background noise.

The actual fracturing activities are likely to occupy only a few days in the life of a well which might be producing for tens of years. However a ~ 3 M_L event is not likely to be associated with the fracking but with fluid movements thereafter (due to pumped water encouraging movement of faults). The UK Government's Chief Scientific Adviser, Sir John Beddington, asked the Royal Society and the Royal Academy of Engineering to carry out an independent review of the scientific and engineering evidence to inform government policymaking about shale gas extraction in the UK, see [Shale gas extraction in the UK](#). Robert Mair, who chaired the review, has been quoted as saying, " We found that well integrity is of key importance but the most common areas of concern, such as the causation of earthquakes with any significant impact or fractures reaching and contaminating drinking water, were very low risk".

Figure 10 Natural seismicity (red) and coal mining-induced seismicity (green) in the UK from 1382 to 2012 (Source: British Geological Survey)

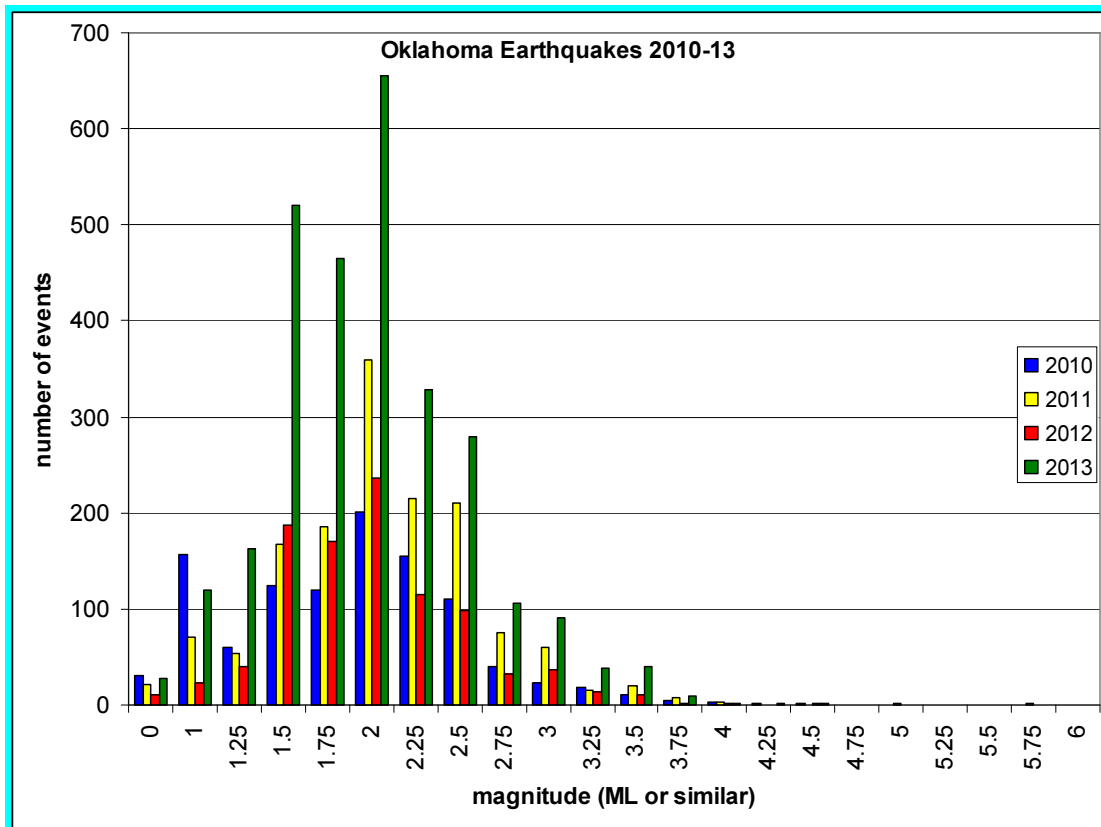


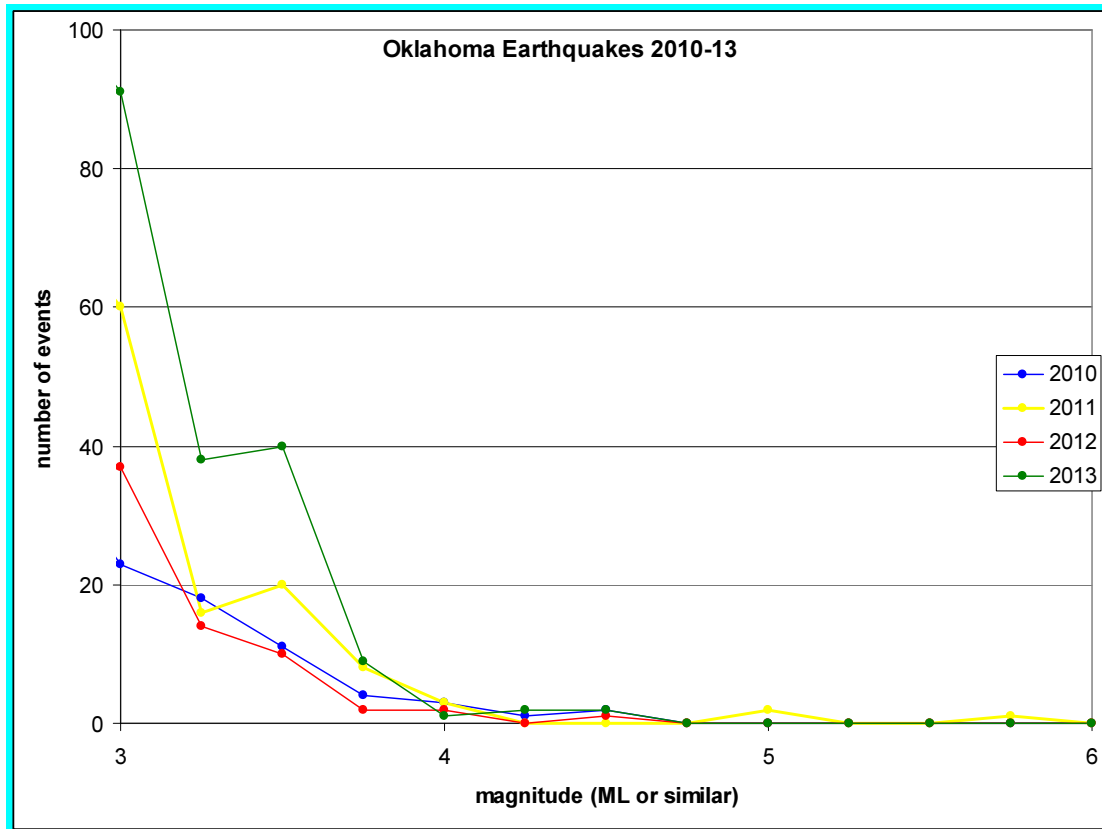
Earthquake Evidence from Oklahoma - added 4th August 2014

Recent reports in the press have suggested that Oklahoma has suffered a marked increase in seismic events since the advent of fracking there. I have examined the evidence for this using the Oklahoma Geological Survey Observatory site <http://www.okgeosurvey1.gov/pages/home.php> as the source of data. The Figures below compare the number of earthquakes of each magnitude range in the last complete year (2013) with the preceding three years (2010-12). 2013 does appear to be significantly worse.

However the statistical significance is not entirely obvious. It would have been nice to get data for earlier years as well, but data for years 2009 and before appear to have been obtained in a different manner since no data was recorded below magnitude 2. I have therefore not used this earlier data since it seems not to be compatible.

However, one might argue that it is not the increased incidence of trivial earthquakes which matters. Rather the concern might be for an increased probability of large, damaging earthquakes. However, the most damning data are for the worst recorded earthquakes in Oklahoma. The top 33 in terms of ML magnitude are listed in the Table below. The third in the list is from year 1882, so data has been collected at least from that date. Alarmingly, 20 out of the 33 worst earthquakes occurred in the five years 2010 to 2014 (and this data extends only to 6th June 2014 as I write). These lie in the magnitude range 4 to 5, except for one at 5.6.





Number of Oklahoma Earthquakes 2010-14

| Year | Number of recorded events | Number of earthquakes felt | Greatest magnitude |
|--------------------------|---------------------------|----------------------------|--------------------|
| 2010 | 1047 | 103 | 4.7 |
| 2011 | 1470 | 99 | 5.6 |
| 2012 | 980 | 75 | 4.4 |
| 2013 | 2848 | 284 | 4.5 |
| 2014 (to 6/6/14) | 2270 | 430 | 4.5 |
| 2104 scaled to full year | 5180 | 980 | - |

The number of earthquakes being felt by people in Oklahoma (which aligns roughly with the number of events above magnitude 3-point-something) has been increasing steeply.

As stated above, this increased incidence of earthquakes is not associated with the fracking per se, i.e., with the actual operation of hydraulic fracturing, but with the use of large volumes of pumped water in the associated deep bore holes.

Oklahoma's Most Severe Earthquakes

| Date | Mag |
|-------------|-----|
| 2011-Nov-06 | 5.6 |
| 1952-Apr-09 | 5.5 |
| 1882-Oct-22 | 4.9 |
| 2011-Nov-08 | 4.8 |
| 2011-Nov-05 | 4.8 |
| 2014-Mar-30 | 4.5 |
| 2013-Dec-07 | 4.5 |
| 1974-Feb-15 | 4.5 |
| 2013-Apr-16 | 4.4 |
| 2012-Apr-03 | 4.4 |
| 2010-Oct-13 | 4.4 |
| 1939-Jun-01 | 4.4 |
| 2014-Apr-07 | 4.3 |
| 2010-Nov-24 | 4.3 |
| 1926-Jun-20 | 4.3 |
| 2014-Mar-30 | 4.2 |
| 2014-Apr-06 | 4.2 |
| 2013-Apr-16 | 4.2 |
| 1997-Sep-06 | 4.2 |
| 1959-Jun-17 | 4.2 |
| 2014-Feb-09 | 4.1 |
| 2014-Apr-10 | 4.1 |
| 2014-Apr-05 | 4.1 |
| 2013-Dec-29 | 4.1 |
| 2010-Feb-27 | 4.1 |
| 1995-Jan-18 | 4.1 |
| 1961-Apr-27 | 4.1 |
| 1956-Oct-30 | 4.1 |
| 2011-Nov-06 | 4 |
| 2014-Mar-30 | 4.0 |
| 1990-Nov-15 | 4.0 |
| 1959-Jun-15 | 4.0 |
| 1929-Dec-28 | 4.0 |

Will shale gas/oil extraction use huge quantities of water?

No.

This has been one of the claims made by the anti-lobby. In perennially drought-ridden States like Texas it is understandable that people would be concerned about water usage. I quote one source which appeared to be reliable regarding the experience in the USA:-

"There is no question that hydraulic fracturing uses a lot of water: It can take up to 7 million gallons to frack a single well, and at least 30 percent of that water is lost forever, after being trapped deep in the shale. And while there is some evidence that fracking has contributed to the depletion of water supplies in drought-stricken Texas, a study by Carnegie Mellon University indicates the Marcellus region* has plenty of water and, in most cases, an adequate system to regulate its usage. The amount of

water required to drill all 2916 of the Marcellus wells permitted in Pennsylvania in the first 11 months of 2010 would equal the amount of drinking water used by just one city, Pittsburgh, during the same period, says environmental engineering professor Jeanne VanBriesen, the study's lead author. Plus, she notes, water withdrawals of this new industry are taking the place of water once used by industries, like steel manufacturing, that the state has lost. Hydrogeologist David Yoxheimer of Penn State's Marcellus Center for Outreach and Research gives the withdrawals more context: Of the 9.5 billion gallons of water used daily in Pennsylvania, natural gas development consumes 1.9 million gallons a day (mgd); livestock use 62 mgd; mining, 96 mgd; and industry, 770 mgd".

**"Marcellus" is the geological name for one of the US's shale deposits.*

As regards the British opinion, the Royal Society review states, "Estimates indicate that the amount needed to operate a hydraulically fractured shale gas well for a decade may be equivalent to the amount needed to water a golf course for a month; the amount needed to run a 1,000 MW coal-fired power plant for 12 hours; and the amount lost to leaks in United Utilities' region in north west England every hour" quoting the source as Moore (2012), *Gas works? Shale gas and its policy implications*, Policy Exchange: London, <http://www.policyexchange.org.uk/images/publications/gas%20works%20-%20feb%2012.pdf>

I conclude that inordinate water usage is not an issue.

Are the additives used in the fracturing fluid kept secret?

No.

There was, at one time, some controversy in the USA about this, but I think that drilling companies have now published the content of their drilling/fracturing fluids. In Britain there is a legal requirement to disclose their contents. They are typically ~95% water and ~5% sand (the "proppant" which holds the fractures open) with ~0.17% chemical additives. The latter are mostly lubricants and viscosity reducers, scale inhibitors, acids (to assist fracturing) and biocides to kill off bacteria.

Where does the water end up?

Typically about one-third of the water is not seen again, i.e., it remains in the shale deposits, with two-thirds re-emerging from the well as "produced water". However, this fraction is highly variable and insufficient experience exists as yet to judge what it will be in UK shales. The produced water is not the same as it was when it was injected. It picks up water from the shale and hence becomes saline and entrains methane and contains a wide range of organic and inorganic compounds from the shale. Since virtually anything that is dug up from depth is radioactive to some degree, so is the produced water.

The produced water can be re-used by injecting back into the well, and this is encouraged to minimise both water usage and the volume of waste water. Drill sites must have temporary waste water storage facilities. In the US open ponds have been used, but in the UK these are not permitted and closed-loop storage tanks would be required. Ultimately the waste waters must be disposed of permanently, possibly in purposed-drilled disposal wells. There is a raft of existing regulations in the UK including the Mining Waste Directive, the Water Framework Directive, the Borehole

Sites and Operations Regulations 1995 and the Radioactive Substances Regulations. (From what I have read, radioactivity is unlikely to be a significant problem).

I haven't looked into this issue in great depth but if I were to spend more time on fracking then the safe, effective disposal of waste waters would be the area to address in more detail. Is "fracking" any worse in this respect than existing well and mining operations?

Could the fractures propagate to aquifers and hence pollute water sources?

It seems not, at least in theory.

The hypothesised threat is that the deep-injected fluids could migrate into groundwater via a network of fractures from the shale layer to the relatively shallow aquifers. Sources I have seen claim that basic geology prevents such a mechanism. A fracture caused by the drilling/fracking process would have to extend through the several thousand feet of rock that separate deep shale gas deposits from freshwater aquifers. The intervening layers of rock have distinct mechanical properties that would prevent the fissures from expanding the required mile or more toward the surface.

This mechanism was considered by the 2010 review sponsored by Cuadrilla, specific to the Bowland shale geology: "In the worst case, the fluid could migrate upwards along a potential fault plane by 2000 ft. Because of the presence of a very thick impermeable formation overlying the Bowland shale and the Permian anhydrites that will act as barrier, there is negligible risk of fluid breaching into permeable layers".

The Royal Society review, [Shale gas extraction in the UK](#), also considers this postulated mechanism and likewise concludes it to be of very low risk.

Has deeply injected water ever migrated into drinking water?

Debatably, yes - once.

There is one case that I have seen which does seem to require close attention. This is the town of Pavillion, Wyoming. In 2010, the US Environmental Protection Agency (EPA) issued a draft report saying that the controversial practice of fracking was to blame for the pollution of an aquifer below Pavillion – the first time such a claim had been based on a scientific analysis. (I have taken a brief look at the report and it does look like a catalogue of nasties were found in the water samples, including compounds identifiable as being from the shale strata - the draft report is available on my web site).

The study drew heated criticism over its methodology and awaited a peer review that promised to settle the dispute. Strangely, and to the great surprise of environmentalists and energy industry supporters alike, the EPA announced in June this year that it was handing over the leadership of these Pavillion investigations to Wyoming State. The report will not now be peer reviewed or finalised. The EPA thus appears to be backing-off from the controversy. The research by the State of Wyoming will be funded by EnCana, the very drilling company whose wells may have caused the contamination. So this turn-around by the EPA stinks.

Moreover, Obama is currently laying out a plan to combat climate change that rests heavily on the use of natural gas. I know nothing about American politics, but it does not take a genius to figure out that the EPA, a federal body, might just have got lent on about making negative waves in regard to natural gas. Meanwhile, the EPA

remains committed to producing a highly anticipated "national study on hydraulic fracturing" - but they are now saying that it will not be before 2016, conveniently just at the end of Obama's term of office. More fishy smells.

On a slightly more positive note, I have seen one source which claims that Pavillion's aquifer sits only a few hundred feet above the gas cache, far closer than aquifers atop other shale gas fields. If it is true that Pavillion is a case of fracking fluid seeping into groundwater directly from the shale strata, the lesson may be to avoid relatively shallow shale deposits in future. So Pavillion may not be fatal to the technology but just a valuable lesson. In general the fears that the fracking fluids will migrate upwards through fractures into the aquifers seem over blown.

The more significant risk is the more mundane one of surface spillage of either fracking fluids or waste water, and/or losses of these fluids from the wells due to fault well casings. The US experience is that 1%-2% of fracking wells have had faulty casing concrete, so this is a significant risk.

Could well blowouts happen?

Of course.

All oil/gas wells are potentially subject to blowouts, and blowouts have happened on fracking wells in the US. The threats are to the safety of the workers and the pollution that would result from an uncontrolled flow of fracking fluids, oil, etc. Once again, though, I cannot see anything unique to fracked wells here. A conventional oil well will kill people and cause pollution if it blows-out. Since Deepwater Horizon we all know about the protective role of the Blowout Preventer (and various other valves). So this comes down to sound engineering build and operation, as per usual.

Is it green? What about climate change?

- (a) If the availability of shale gas leads to decreased coal burn then this is green. This appears to be what has happened in the states.
- (b) If the availability of shale gas leads to more gas-powered vehicles, thus displacing petrol/diesel, then this is green also.
- (c) If shale gas displaces renewables in electricity production, this is non-green - and this is what the Green movement fears and stresses, probably with justification.
- (d) If shale gas displaces nuclear in electricity production then this is non-green also.

As regards (c), the Greens are probably right to be concerned. The House of Commons Energy and Climate Change Committee carried out an inquiry into shale gas in 2011. The inquiry considered the potential carbon footprint of large-scale shale gas extraction and implications for the UK of large scale shale gas production around the world. The Committee concluded that if a significant amount of shale gas enters the UK market (whether from domestic or foreign sources), it will probably discourage investment in more expensive, lower carbon emission renewables.

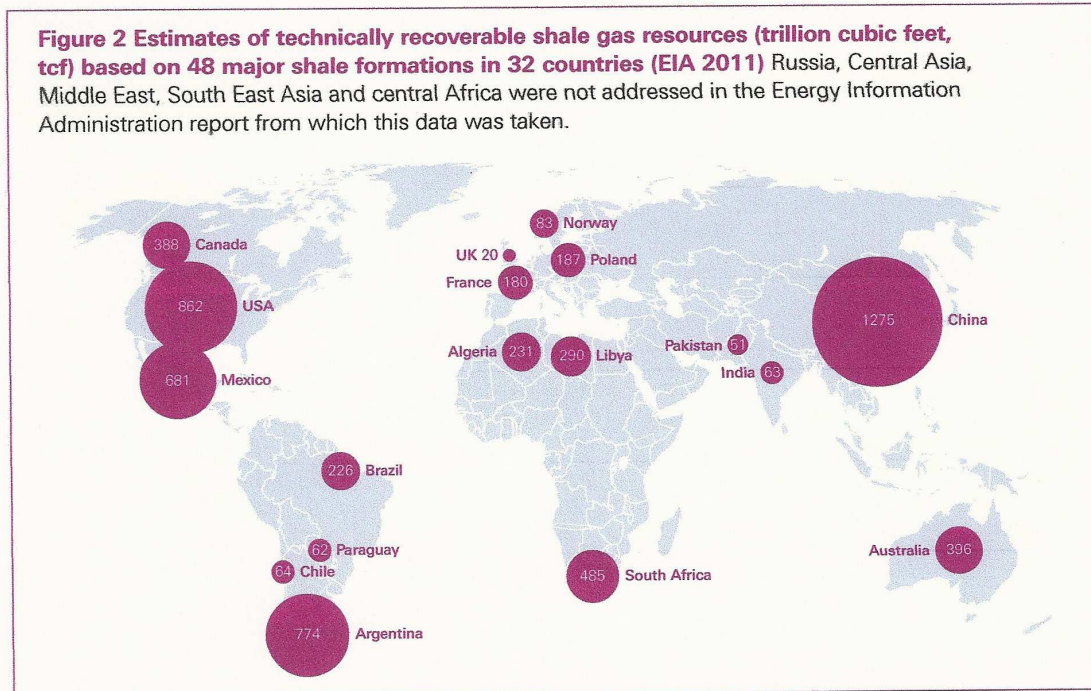
This is essentially confirmed by President Obama whose strategy to combat climate change rest heavily on the use of natural gas. I presume this is based on (a), above.

Gas extraction also has a direct effect on climate change since some methane inevitably escapes, and methane is a stronger greenhouse gas than CO₂ (although it's half-life in the atmosphere is shorter). Industry officials concede that they could be losing anywhere between 1 and 3 percent, which seems worryingly high to me.

In summary, I'm not convinced that shale gas extraction is green. It is tricky to see which of the above issues wins.

How much shale gas is there in the UK?

No one will know for sure until a fair number of wells have been explored. However estimates are that there will be ~20 trillion cubic feet of recoverable gas (though I have also seen estimates of ~50 tcf). This is actually quite tiny compared with the other 17 countries shown below...



This compares with the UK's annual gas usage of ~3 trillion cubic feet. So shale gas alone could keep us in gas only for ~7 years - unless existing estimates are very wide of the mark. However, in the current energy climate it may be more significant to observe that if shale gas made a 20% contribution then we're looking at 35 years.

Will "fracking" be a blot on the UK landscape?

I don't know, but the large number of wells required is a significant concern.

But I expect there is little difference between a fracked well and any other gas/oil well in this respect. Fracking technology does have the advantage of long horizontal well sections which means that one drill site can extract from within a circle of radius several miles. Conventional wells might have required many separate drill sites.

The Greens will frighten you with pictures like this,



...but does it really have to look like this? I suspect not. Here's three others that don't look so bad...





For me the issue is the spacing between wells. I have seen sources claiming 8 to 16 wells per square mile. I find this odd, though, since horizontal well bores of a mile in length (and assuming many bores are possible in a range of directions) would imply a 2 mile spacing between wells. I suspect these two scenarios would make a huge difference to the visual impact.

To extract the 20-50 tcf of UK shale gas will require between many thousands and a few tens of thousands of wells. All these would require vehicular access. Trucks and tankers would need to visit, possibly quite regularly. Whilst the US has been able to absorb ~500,000 wells, I suspect they have the wide open, and sparsely populated, regions available to do so. In crowded Britain it would be another matter. I find this aspect to be of significant concern.

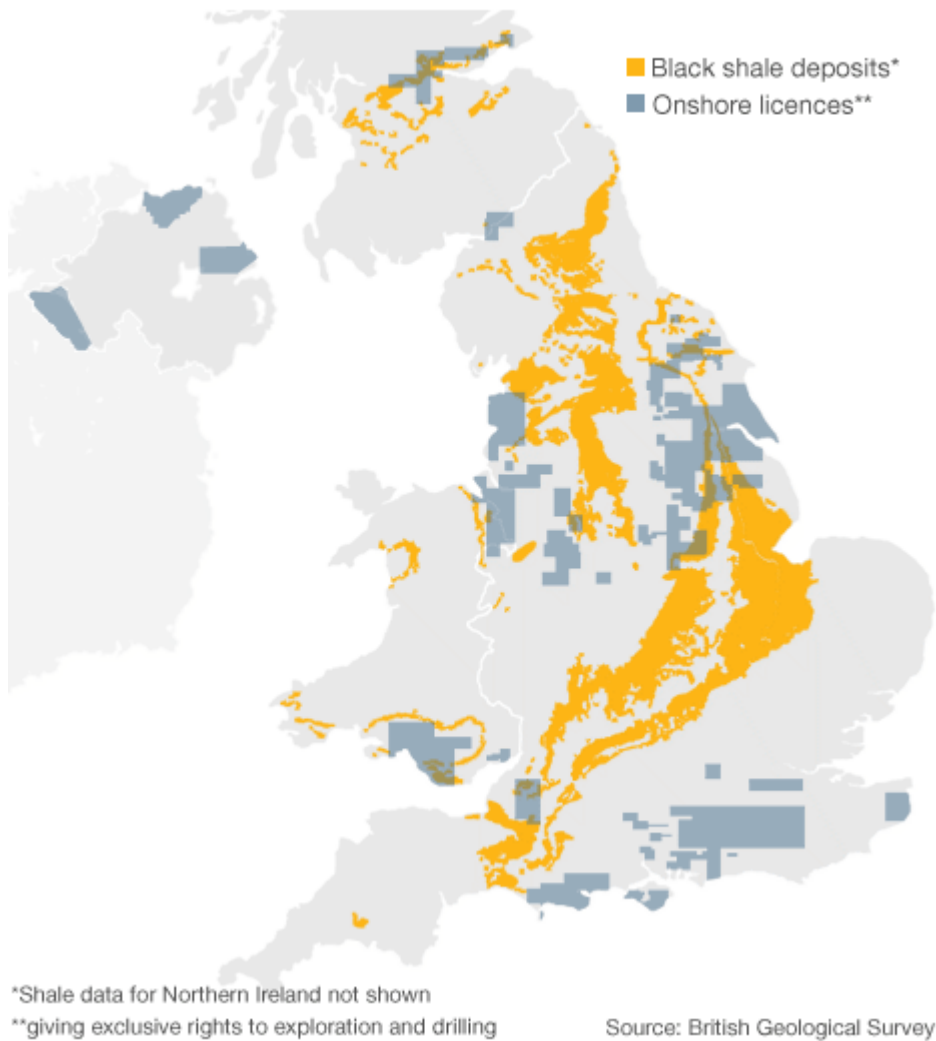
Will shale gas/oil production be commercially viable in the UK?

This is not a question which we need be concerned about - unless you happen to be an employee of, or an investor in, a company involved in such operations. The matter will settle itself: it will only happen on a significant scale if it is profitable to do it. Admittedly this may depend upon the prevailing tax, market place and regulatory regimes, which may be subject to policy decisions by government - and thereby be influenced by environmental issues and climate change pressures.

I'm expecting it to happen.

However, there may be competition from the newly emerging techniques for extracting further reserves from North Sea wells now becoming exhausted using current procedures. (The new techniques involve injecting lower viscosity fluids of one sort or another, including the possible use of captured CO₂).

Shale formations across the UK



Conclusion?

Fracking *per se* is not an issue. The issues are associated with large scale inland extractions in an overcrowded island. The most significant problems are,

- Potentially serious deleterious impact on the landscape, and the need for regular, heavy vehicles to access extensive areas previously 'unspoilt';
- Poor well integrity leading to fracking fluids causing pollution;
- Storage and ultimate disposal of waste waters.

The latter two points are essentially 'routine' issues which should be possible to address through good engineering design/build and operation. Neither are unique to "fracked" wells, or even to wells in general (mining and industrial activities can have similar issues). The first bullet is of greater concern since it may be unavoidable. Also,

- Information emerging from the USA on the increasing numbers of earthquakes of significant severity following fracked well usage needs careful watching. It currently appears slightly alarming.