A Review and Synopsis of the Scientific and Technical Evidence Against Hydraulic Fracturing (or 'Fracking').

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On behalf of Frack-Free Wales

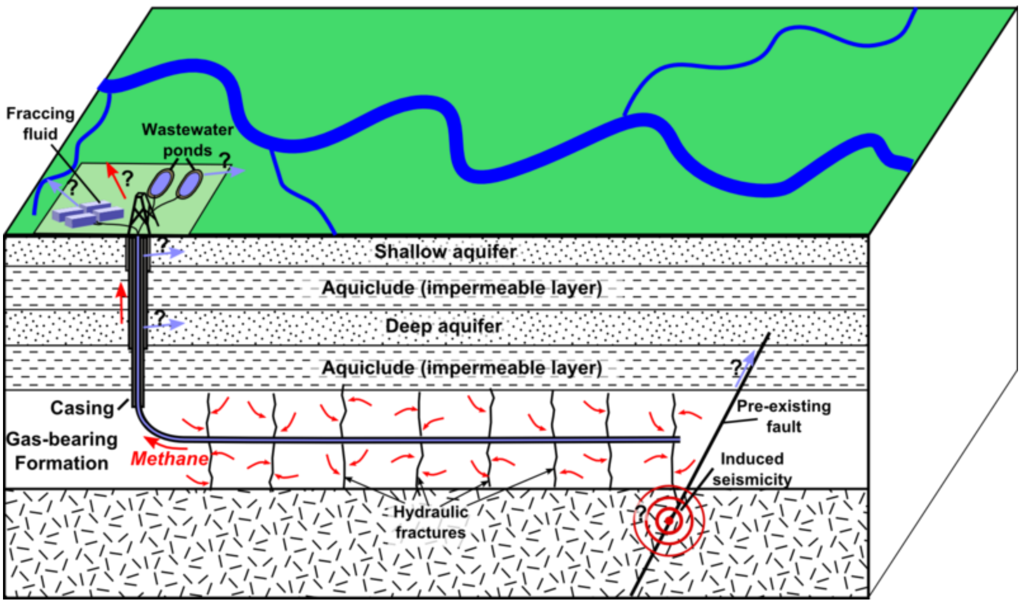
INTRODUCTION

The technical and scientific problems/issues with the new generation of hydraulic fracturing (fracking) methods span the spectrum from the molecular to the global scales. The key differences between traditional 'conventional' fracking and the recent so-called 'unconventional' innovations of the last 15 years are summarised in Table 1[1]:

	CONVENTIONAL DRILLING	UNCONVENTIONAL DRILLING
Well type	Vertical	Horizontal
Well pad footprint	1 to 3 acres	3 to 6 acres
Water requirement per frack	20,000 to 80,000 gallons	2 to 9 million gallons (ave. 4mill)
Chemicals required	Few	Many and varied
Fracking frequency	Rarely	Frequently
Nature of resource	Large pocket of resource; easy to extract	Scattered throughout the rock; hard to extract

Table 1

The unconventional process is shown schematically in Figure 2 [2]. Note the 7 question marks, which highlight just some of the problem areas.



? = (Left to right, top to bottom): frack fluid spills; blow-outs and pressure release vapourisation; safe handling and disposal of produced wastewater; poor fitting casements and leaks into soil/regolith near the surface; contamination of deep aquifers through cement faults; pre-existing faults through aquiclude exacerbated by fracking itself; seismic activity creating new faults, extending existing ones; destroying integrity of casings.

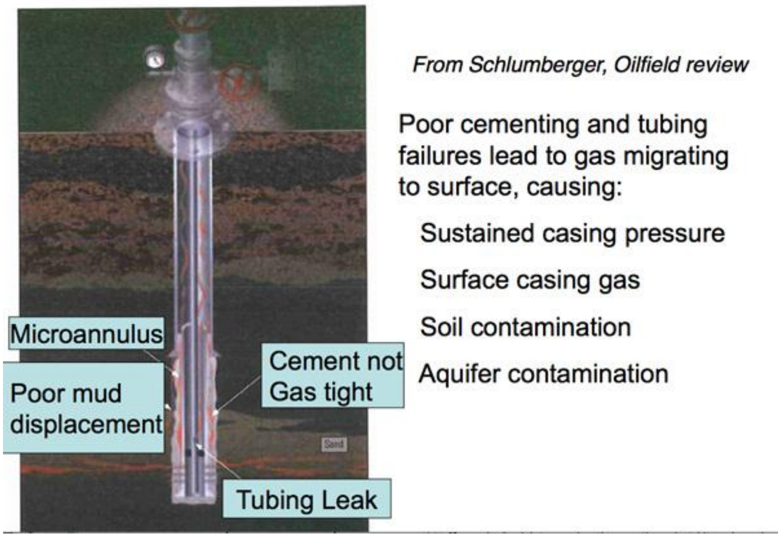
[1] Paleontological Research Institute paper: http://www.museumoftheearth.org/files/marcellus/Marcellus_issue6.pdf

[2] MJ Whiticar, Biogeochemistry Dept., University of Victoria, British Columbia: http://www.energybc.ca/profiles/naturalgas/fracking.html#frackingdiagram

Borehole Casings

Once the drilling has taken place, the process of casing the borehole is undertaken. This is the process that is supposed to ensure there are no subterranean water contamination issues. "*It's an engineering process that is too hard to do perfectly,*" said Tony Ingraffea, a professor in Cornell's School of Civil and Environmental Engineering, "*even with the best personnel, cements and equipment*."[3] He has found that some leaking (of gas and fluid) is inevitable due to failures in the metal casing or cement, contaminating underground sources of drinking water and damaging air quality. In fact, statistics show that even new wells fail and that a higher percentage fails with age. The gas industry has been studying the ongoing problem for decades, and knows these statistics full well.

In a report entitled "*Well Integrity Failure Presentation*", drilling service company Archer reports that nearly 20 percent of all oil and gas wells are leaking worldwide. A 2003 joint industry publication from Schlumberger, the world's No. 1 fracking company, and oil and gas giant ConocoPhillips, cites astronomical failure rates of 60 percent over a 30-year span.[4]



The casings fail for many reasons: failure to ensure gas tight fitting of the metal components; the technical difficulties of ensuring consistent flows and quality in the cement (just about impossible with such long and non-straight boreholes); ground shrinkage around the boreholes; poor mud displacement; and seismicity (natural or induced) destroying the integrity of the cement and distorting the fit of the metal casings.

SEISMICITY

With reference to seismicity, not only is fracking highly likely to induce it[5], but the sorts of area that are being explored in the UK are amongst the most seismically active parts of the country. The recent quake in Leicestershire, while not fracking related, would have been more than enough to threaten the integrity of borehole casings for

[3] http://www.news.cornell.edu/stories/June12/DCfracking.html

[4] http://www.timesunion.com/opinion/article/Fracking-is-hardly-leakproof-3646458.php

[5] http://science.time.com/2011/12/12/fracking-sizing-up-the-quakes-that-come-from-hydraulic-fracturing

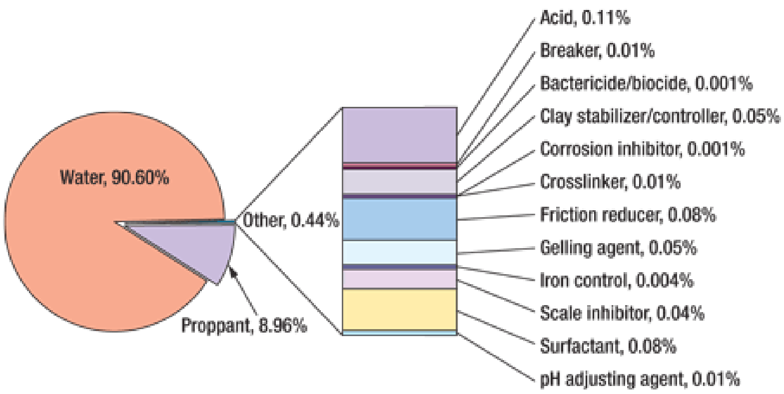
many miles around. Parts of Leicestershire are in the frackers sights. The lies and deceit of people in the industry are demonstrated by Cuadrilla's CEO stating on BBC television that: *"There are procedures we can put in place to practise earthquake prevention"* [6] . The fact of the matter is that, to quote the US Geological Survey, ***"****People can't stop earthquakes from happening. People can significantly mitigate their effects by identifying hazards, building safer structures, and learning about earthquake safety"* [7]. Fracking is, patently, the absolute antithesis of earthquake mitigation.

EXPLOSIVE FRACTURING

Once they have drilled into the gas bearing rocks (e.g. shale) the next stage is the triggering of explosions at regular intervals along the horizontal section of the borehole within the target strata. Predicting the extent of the resultant cracks is hard enough in a theoretical model, but in absolute terms is impossible due to the vagaries of deep subterranean geology. Pre-existing faults can be very difficult to identify by current survey techniques. Very minor ones can also be accentuated by the fracking explosions. Fractures can extend for 2500 ft and are frequently up to 1000ft. They can spread to neighbouring strata and through the target strata to neighbouring wells [8].This means that there is no assurance that the aquiclude layer is secure above the target strata, either before or, especially, after fracking operations.

HYDRAULIC FRACTURING (fracking)

Once the explosive fracturing has happened, the hydraulic fracturing is undertaken to extend the fractures still further and prop them open with sand. With the old conventional methods, there was rarely any need to use more than water and sand (the sand acts as the proppant in the cracks). But the newer unconventional methods (because of the length of boreholes, the drilling technology, the high pressures being used and the nature of the geology) require a whole cocktail of chemical additives to facilitate the processes. The industry itself admits to the frequent need for the following ingredients [9]:



[6] http://www.bbc.co.uk/news/uk-england-lancashire-15550458

[7] http://earthquake.usgs.gov/learn/topics/megaquakes.php

[8] static.ewg.org/reports/2011/fracking/cracks_in_the_facade.pdf

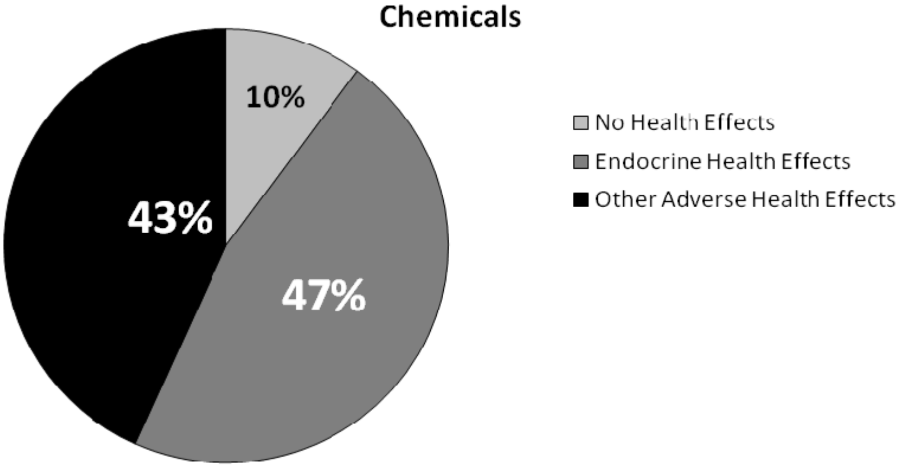
[9] http://www.worldoil.com/Marcellus-groundwater-claims-A-case-for-scientifically-informed-decisions.html

- Strong acids to dissolve minerals
- Numerous poisonous biocides to eliminate bacteria and algae
- Friction reducers such as acrylamides and mineral oils
- Corrosion inhibitors to protect drills and well casings (cont.>)
- Scale inhibitors to prevent furring
- Surfactants and cross-linkers to adjust fluid viscosity
- Acidity regulators
- Breakers
- Iron control agents [10]

HEALTH IMPACTS OF FRACK CHEMICALS

The leading authority on the health impacts of the chemicals used in fracking is Dr Theo Colborn, of the world renowned TEDX (The Endocrine Disruption Exchange) [11]. Doctor Colborn has identified a wide range of compounds in frack fluids and discerned a staggering array of serious health consequences that range from the immediate to the slow developing. In many cases only minute concentrations can cause devastating consequences (parts per billion)[12]. Over 78% of the chemicals are associated with skin, eye or sensory organ effects, respiratory effects and gastrointestinal or liver effects. The

Figure 2: Percent of Products Used in Natural Gas Production Containing Endocrine Disrupting Chemicals



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[10] See the Congressional Committee sequence near the end of the Gasland film. (from 5:00 of this clip: http://www.youtube.com/watch?v=VWYCxY9dx5w)

[11] http://www.endocrinedisruption.com/chemicals.introduction.php

[12] http://www.endocrinedisruption.com/files/Multistatesummary1-27-11Final.pdf

brain and nervous system can be harmed by 55% of the chemicals. Other effects, including cancer, organ damage, and harm to the endocrine system, may not appear for months or years later. Between 22% and 47% of the chemicals were associated with these possibly longer-term health effects.

DISCLOSURE OF CHEMICALS

There are well documented issues with disclosure of the chemicals used in the USA (the infamous 'Halliburton loophole') [13] and frequent misconceptions that we are assured of full disclosure of chemicals in the UK. This is a dangerous myth. Assurances about the EA requiring full disclosure of chemicals used in fracking are undermined by a few inconvenient truths. There is no such thing as proprietary frack fluid. You do not buy it off the shelf, with a nice contents label and a MSDS. It varies at every fracking stage and with variations in local geology. You would need a presence at every single 'frack job', at every single site, to sample the fluid used every time. This is a practical impossibility. So the EA asks the industry to declare what it is using. The deceits that UK frackers, Cuadrilla and their friends, tell about the chemicals they use are well established [14].

The EA undertook some analysis of the flowback waters from the fracking operations in Lancashire [15]. Despite the high profile of this, the first fracking in the UK, the analysis only looked for one of the declared frack fluid ingredients, polyacrylamide, in one solitary sample (and found it). They acknowledged that this is known to break down into the nerve toxin acrylamide (see pg3). They also conclude that the levels of various radioactive isotopes (radium-226, potassium-40, radium-228, plutonium-241) now necessitate a permit if Cuadrilla want to continue disposing of these fluids to the nearest waste water treatment works (c.40 miles away), because the levels measured, combined with the expected quantities of flowback fluid, exceed new (but arguably still inadequate) limits.

What the analysis did not mention was the particularly toxic BTEX compounds (benzene, toluene, ethylbenzene, and xylenes) found in petroleum derivatives. Cuadrilla never publicly mentions using such things, but it is admitted on a

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[13] http://www.independentwatertesting.com/education-center/148-what-is-the-halliburton-loophole.html

[14] See the second half of: http://bridgendgreens.wordpress.com/?s=fracking+cuadrilla

[15] http://www.environment-agency.gov.uk/static/documents/Business/6th_Dec_-_Shale_gas_-_North_West_-_Monitoring_of_flowback_water_-_update_%283%29.pdf

data sheet [16], under the guise of 'hydrocarbon oil'. It would appear that the EA did not even attempt looking for this – or the non-specific biocides Cuadrilla also own up to using, without ever being specific.

HANDLING FLOWBACK WATER

It is believed by local campaigners that some flowback water was discharged into the Manchester Ship Canal, after treatment at the Daveyhulme Water Treatment plant, but before the EA analysis was able to be done. The reality is that the treatment plants would have nowhere near enough capacity to handle the massive quantities of flowback that full scale production would generate, and it would be difficult and costly to eliminate all the toxins. Currently the flowback fluid is being stored in double skinned tanks on site pending a permit application. To be fair, Cuadrilla is not taking any chances. In their own words: *"Upon returning to the surface, they* [frack fluids] *are stored in steel tanks and at no point come in contact with the ground. In the unlikely event that any liquid was spilt on the surface, seepage at ground level is prevented by the installation of an impermeable membrane on land at and surrounding the well site."* [17] Extraordinary precautions, I would suggest, for fluids we are told we should not worry about. Storage is one thing, but avoiding spills while transferring fluids to tanker trucks, for example, is another [18].

SILICA SAND

Over and above the issues with chemicals, the sand used in unconventional fracking has serious health issues too. The best sand to use as a proppant in frack jobs is 99% silica sand, because of its hardness and grain shape. However, there is now well established research that handling such sand, and breathing in the dust from it, is a very serious health risk. The medical journal, the Lancet, cites research that shale gas workers around the world are experiencing unacceptable risks of silicosis – which is debilitating, irreversible and has no cure. [19]

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[16] http://www.cuadrillaresources.com/wp-content/uploads/2012/02/Chemical-Disclosure-PH-1.jpg

[17] http://www.cuadrillaresources.com/what-we-do/technology/fracturing-fluid/

[18] http://www.minutemanspill.com/hydraulic-fracturing-fluid-services/

[19] http://download.thelancet.com/flatcontentassets/lanres/edch/131112_1_3.pdf

AIRBORNE POLLUTION

Airborne pollution is not confined to silica dust, and is increasingly seen as a major issue with fracking activities. A major study by the Colorado School of Public Health, entitled *"Human Health Risk Assessment of Air Emissions from Development of Unconventional Natural Gas Resources"* [20], has shown that air pollution caused by fracking may contribute to acute and chronic health problems for those living near natural gas drilling sites. There is considerable anecdotal evidence of aggravated breathing/lung problems in the aftermath of the Lancashire fracking incidents. "*The health science community is now looking at why health complaints are rising in fracking areas, particularly among children*," says Steinzor of Earthworks [21]. She says that some people who live near fracking areas have been complaining of headaches, nausea, bloody noses and nerve problems.

The sources of the air pollution are considered to be from two main sources. One is the large amount of very heavy diesel powered machinery used in the drilling and fracking operations. Typically the pumping equipment would amount to *"a maximum pressure rating of 20,000 pounds per square inch, and a power rating of 2000 hydraulic horsepower each, with all twelve pumps totalling 24,000 horsepower"* [22].

The second serious source of air pollution is from methane leaks and fugitive emissions [23]. With the methane comes a variety of other volatile organic compounds (VOCs) which can contribute to the formation of smog. Even where these gases are flared, the gas flare can also lead to the formation of secondary pollutants, such as sulphur compounds, and of nitrogen oxides which also increase air pollution. The health effects of these compounds are well documented [24].

[20] http://www.sciencedaily.com/releases/2012/03/120319095008.htm

[21] http://www.sciencenewsforkids.org/2012/07/fracking-fuels-energy-debate-and-controversy/

[22] http://www.oilandgastechnology.net/upstream/halliburton-technology-used-gas-power-fracking-rigs

[23] http://stop-csg-illawarra.org/csg-risks/leaking-methane/

[24] http://www.endocrinedisruption.com/files/Oct2011HERA10-48forweb3-3-11.pdf

Even if there were no issues with pollution whatsoever, there are 2 massive issues to consider; namely water resource implications and impacts on global warming.

WATER RESOURCE IMPLICATIONS

The scale of water usage in both drilling and fracking is hard to fully appreciate and difficult to ascertain exactly. An independent review of the subject by the Pacific Institute, one of the world's leading non-profit research and policy organisations focussing on creating a healthier planet and sustainable communities, highlighted the confusion and obfuscation of the facts created by the industry. Entitled "*Hydraulic Fracturing and Water Resources: Separating the Frack from the Fiction" [25],* and published in June 2012, it is probably the definitive study on the subject.

It establishes six key water resource issues: (1) water withdrawals; (2) groundwater contamination associated with well drilling and production; (3) wastewater management; (4) truck traffic and its impacts on water quality; (5) surface spills and leaks; and (6) stormwater management.

'Water withdrawals' refers to the water that needs to be withdrawn from existing resources for fracking activities. The report highlights the huge variability in amounts used, but broadly supports established estimates that it takes about 500,000 gallons to drill the average well, and takes an average of about 4 million gallons for each frack job. These figures are huge enough if you are talking about one frack job, in one well, on one well pad. Once you begin to appreciate the potential scale of the industry in the UK, the figures soon become astronomical.

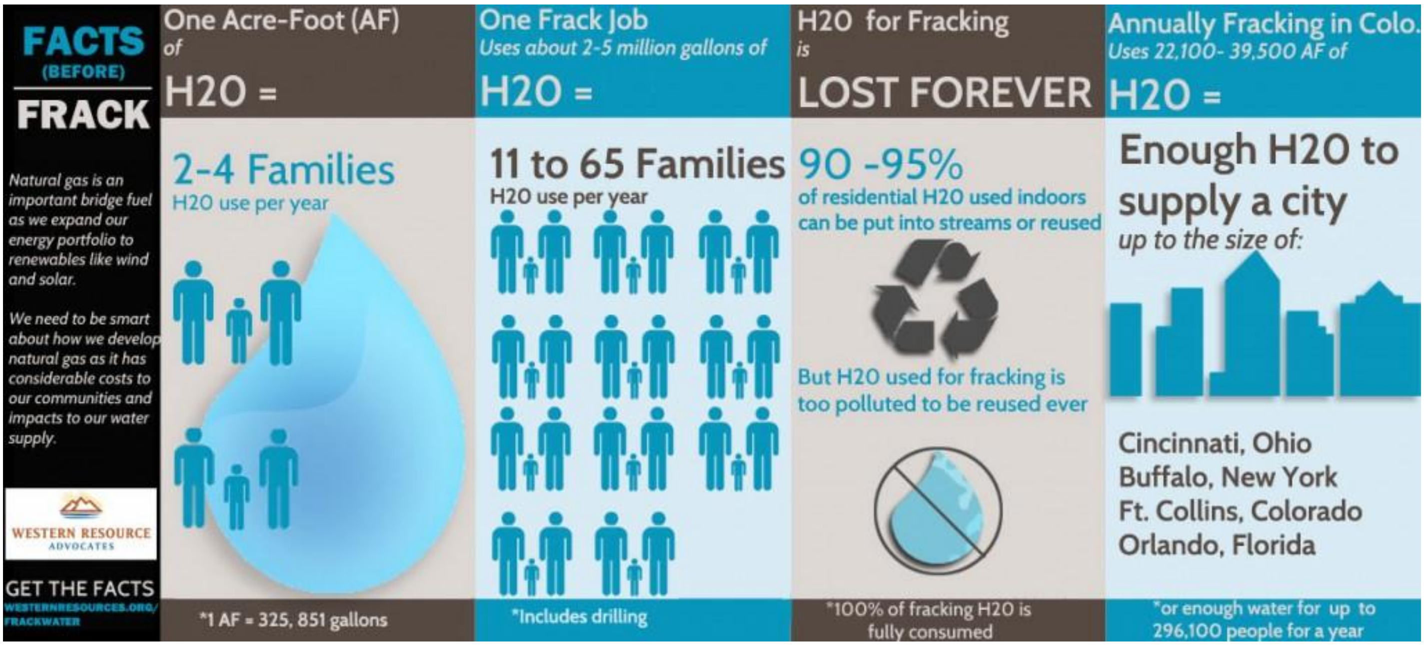
Using industry estimates throughout (probably conservative, at the very least), each well can expect to be fracked about 6 times in its lifetime (range observed in the literature = 3-20). Each well pad will have about 10 wells radiating out from it (range 6 -16). This gives an estimate of 4x6x10 million gallons per well pad = 240 million gallons. Cuadrilla have explicit plans for 80 sites in Lancashire = 19,200 million gallons. This would only be a fraction of the sites needed to exploit the full potential of the Bowland Shale in that part of the country. Current technology would put the optimum spacing of sites at something like 2km apart. Pedl licences cover 10km squares. So that is 25 sites per

[25] http://www.pacinst.org/reports/fracking/full_report.pdf

10 km square. There are about 185 of these 10km squares currently under licence onshore and all are potential targets of the frackers [26].

Continuing the mathematics, this makes an estimated 240x25x185 = a staggering 1,110,000 million gallons of water used for fracking. Add on the water used in drilling (0.5x10x25x185=23,135 million gallons) for a (conservative) estimate of 1,133,125 million gallons of water. This represents well in excess of 2 billion Olympic swimming pools, or approximately 16.5 Lake Windermeres!!

To put this into a fuller context, only about 30% of the water used in fracking is ever recovered. It is often as low as 10% [27]. If the industry is to be believed, it is putting this water safely below deep aquicludes. We have examined reasons to doubt this, but if they are right we are talking about putting water outside the water cycle. It will become (highly contaminated) fossil water that may not see the light of day for many millions of years. In an era of ever increasing pressure on water supplies, for a huge range of reasons [28], it is completely irresponsible to be putting 12 Lake Windermeres worth of precious water supply beyond reach.



(Western Resource Advocates report shows that fracking in Colorado uses enough water to supply 166,000 to 296,000 people for a year for household use[29]. As for gas being a 'bridge fuel', this is considered below.)

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[26] https://www.og.decc.gov.uk/information/bb_updates/maps/landfields_lics.pdf

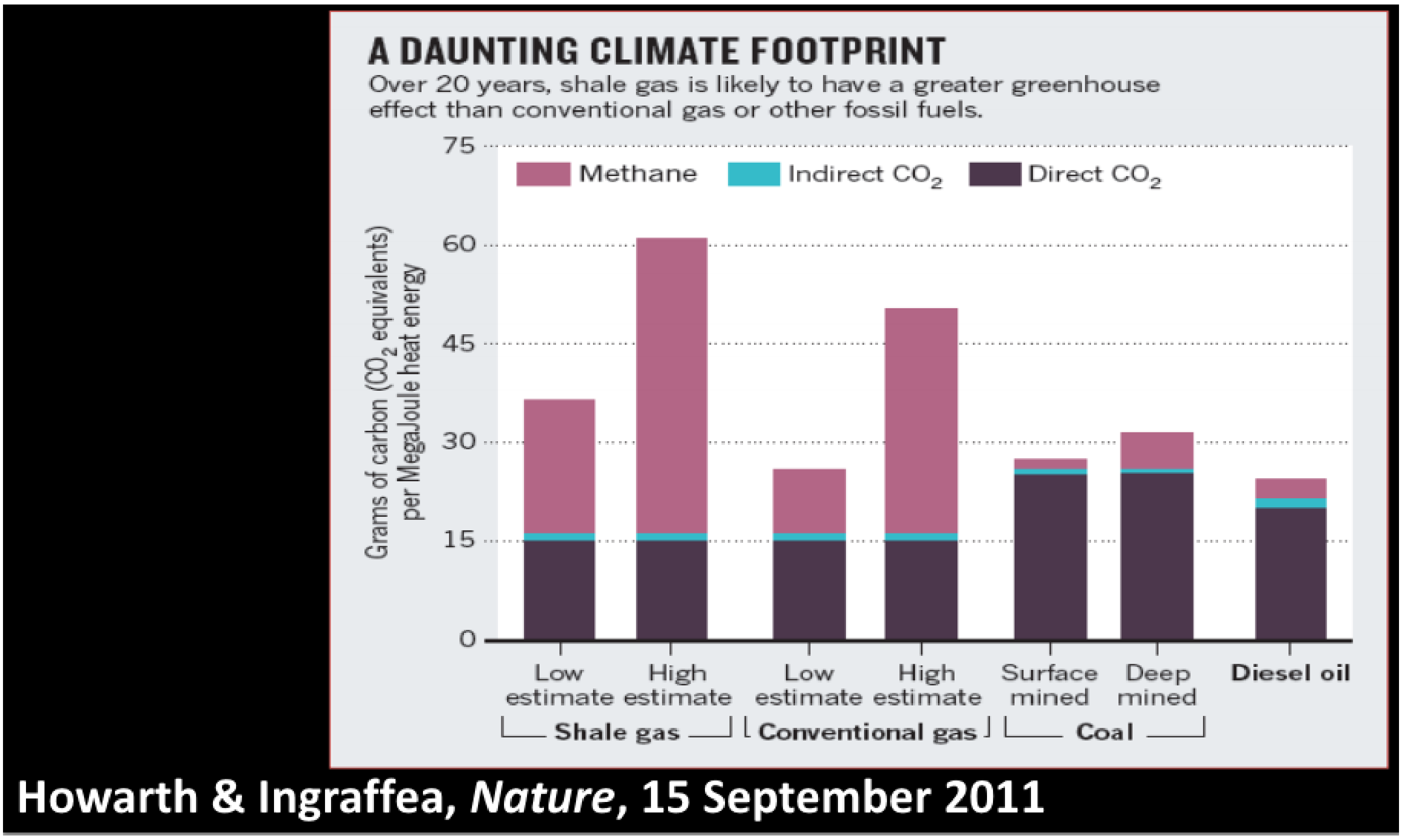
[27] http://www.energyfromshale.org/fracking-fracturing-water-supply

[28] http://cdn.environment-agency.gov.uk/geho1208bpas-e-e.pdf

[29] http://frackfreesprings.org/resources/fracking-our-water/

CLIMATE CHANGE IMPACTS

This brings me to the last major issue – one that can only exacerbate water resource issues - the impact of exploiting shale gas on greenhouse gas (GHG) emissions. The definitive work on this subject has been done by the Tyndall Centre for Climate Change Research, at Manchester University. Its report, "*Shale gas: an updated assessment of environmental and climate change impacts"* [30] is compelling. The report concludes that in an energy hungry world, any new fossil fuel resource will only lead to additional carbon emissions, thereby wrecking claims that shale gas can be seen as a transitional (or bridge) fuel as we move towards a low carbon energy future. Its use can only delay the introduction of renewable energy alternatives by putting off the imperative. "*Consequently, if we are serious in our commitment to avoid dangerous climate change, the only safe place for shale gas remains in the ground*" says Professor Kevin Anderson of the Tyndall Centre.



POPULATION DENSITY

In addition to concerns about groundwater and GHG emissions, the Tyndall Report also points out how important it is, in considering possible shale gas extraction in the UK, to recognise that high population density is likely to amplify many of the issues that have been faced in the US. Those that claim that the US experience

[30] http://www.tyndall.ac.uk/sites/default/files/coop_shale_gas_report_update_v3.10.pdf

cannot happen here are in complete denial of the distinct possibility that the environmental and health consequences could be significantly worse on these relatively crowded little islands of ours.

IN CONCLUSION

In conclusion, allow me to point out that most people's concern over fracking tends to start in a NIMBYist fashion, with concern over related planning applications in their local areas. Witness the ever increasing plethora of local opposition groups across the country, indeed across the world. What invariably happens, however, is that people very quickly learn about and recognise the full range and scale of the issues involved – the issues in this review, and many more such as noise, HGV traffic, property values, loss of amenity, and impacts on biodiversity, agriculture and tourism and so on. We have seen many local opposition groups thereby morph into national and international campaigns, seeking to be mutually supportive towards a common goal. This is an issue that therefore stretches beyond the scientific and technical. It has to become a political issue in which choices about our relationship with the planet we depend on are central.