West Sussex County Council
Minerals Local Plan consultation submission

David Smythe
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[This version contains the diagrams and internet hyperlinks omitted from the online version submitted on 13 March 2017. Extra links added 15 March (v. 1.4)]

1 Introduction

As Emeritus Professor of Geophysics in the University of Glasgow, former employee of the British Geological Survey (BGS) when I was an adviser to government on hydrocarbon exploration matters, and sometime consultant to the oil exploration industry, all spanning a professional career of 45 years, I consider myself to be well qualified to comment on the hydrocarbon aspects of the Minerals Local Plan (MLP). Indeed, I am probably the only person who has ever sat on both sides of the table at UK exploration licence (PEDL) application interviews. In the last three years I have also provided the Planning Committee with detailed technical objections to several proposed hydrocarbon planning applications in West Sussex and the SDNP.

My objection to the draft MLP for West Sussex concerns the wording and the meaning of Section 6.7 dealing with hydrocarbon resource development, within which is included the definitions of unconventional hydrocarbons and of hydraulic fracturing ('fracking'). In this regard, although the plan appears to be consistent with relevant national policy, the plan should depart from such national policy because the definitions used in the latter are unsound.

[This submission is complex and technical in parts, and it is difficult to clarify and justify using only plain text, without diagrams, internet hyperlinks to data sources, and without the use of more sophisticated mark-up tools (headings, emboldening, italicisation, etc.). I am therefore providing an illustrated version of this submission on my website at www.davidsmythe.org/fracking.]

I shall also be happy to submit more information if thought necessary, and to appear in person before the Inspector, if asked, to present my findings and be cross-examined.

2 Unsound or unclear wording

I draw attention firstly to the poorly drafted paragraph 6.7.4 of the MLP:

> "*6.7.4. The strategy for oil and gas is to make provision, subject to there being no unacceptable impact in West Sussex, and the use of hydraulic fracturing, within the definition used in the Infrastructures Act 2015 (and related amendments)33, does not take place within, or have an unacceptable impact on, the South Downs National Park, Areas of Outstanding Natural Beauty, or other protected areas including protected groundwater zones. Major34 oil and gas development not involving high volume hydraulic fracturing should only take place within the South Downs National Park or Areas of Outstanding Natural Beauty in exceptional circumstances and when it is in the public interest.*" [33 and 34 are subscripts in the original referring to footnotes].

The first sentence above does not make sense. Removing the qualifying subordinate clauses, it states:

> *"The strategy for oil and gas is to make provision ... and the use of hydraulic fracturing ... does not take place within ... the South Downs National Park ...."*

For what is provision being made? It needs to be stated. Also it appears that the conjunction 'that' needs to be inserted before 'the use of hydraulic ...'

Lastly, the caveat "*in exceptional circumstances and when it is in the public interest*" is too vague and loose, and the MLP is thereby giving a hostage to fortune. It opens the door for developers to challenge the special protections afforded to national parks, AONBs and so on. A more reasonable statement, in keeping with other local and national policies (including the need to reduce CO_2 emissions), should omit this caveat. The onus would then be on central government, if it were minded to support any particular proposed development infringing the MLP, to call for an inquiry with a view to having the MLP overturned in that instance. It is not rational for the MLP to provide a loophole in advance by the use of such wording.

3 National policy - energy independence

3.1 Introduction

I explain below why certain aspects of national policy are not based on a credible research base or finding of facts (Representations Guidance Notes section 3.2). It therefore follows that the MLP, in following these policies, is similarly not based on a credible research base or finding of facts. The MLP is therefore justified in deviating from national policy (Representations Guidance Notes section 3.4), in order to be founded upon a credible research base and finding of facts.

The Background Document (at paras. 3.182 - 3.187) to the Proposed Submission Draft summarises the current state of local hydrocarbon exploration and national policy. These paragraphs refer in turn to Background Paper 2 on Minerals (dated December 2014) at paras. 4.19 - 4.23 on national policy, and paras. 4.24 - 4.30 on hydrocarbon types and their extraction.

I discuss first national policy, then unconventional hydrocarbons in general, and then hydraulic (and other methods of) fracturing.

In respect of national policy, both the Guidance Notes and the Minerals Background Paper refer to the 2007 white paper '*Meeting the energy challenge*'. I submit that reliance on this white paper is unsound, regarding energy in general, and hydrocarbon development in particular, for the following reasons.

3.2 History of unconventional fossil fuels (UFF)

The exploitation of unconventional fossil fuels (UFF) had barely begun (and in the USA only) by 2007, the date of the white paper. The words *unconventional, hydraulic, fracturing,* and *tight* (in the context of tight oil or gas) are not even mentioned in the white paper. Given that the white paper on energy evidently failed to foresee the rise (and fall) of the entire UFF industry, it should not be relied on a decade later for policy designed to extend from now to 2033.

The development of UFF in the USA has followed a boom and bust cycle. This industry is frequently touted as an example for the UK to follow, but in reality it has been a financial disaster, founded on private investment ('junk bonds') in small- and medium-size independent oil and gas companies. Some 74,000 horizontal UFF wells have been drilled since hydraulic fracturing for shale gas and oil started in about 2003. At a minimum of $6M each, the costs of drilling are therefore at least $440 billion (but probably well over $500 billion if historic drilling costs are used).

The shale gas bubble peaked in 2011-2012, and by 2015 the *Wall Street Journal* reported that the total debt of the companies (excluding the majors Chevron and ExxonMobil) was in excess of $200 billion. The average productive life of wells is 5-8 years, with most of the production being achieved in the first two years. Therefore, since the majority of US wells are five years or more in age, they cannot be expected to produce much more. Five thousand of the Barnett (Texas) shale play's 20,000 wells are now 'shut in' (closed down). Even the recent slight rise in the price of oil has not saved the UFF industry from collapse; the Bakken oil shale play of North Dakota, for which UFF in the Weald is a close analogy, is now in severe decline since peaking in December 2014.

3.3 Carbon emissions

Anthropogenic global warming (AGW) has proceeded apace in the last decade. It is difficult to reconcile the continued burning of fossil fuels, either conventional or unconventional, with the UK's targets and obligations to reduce CO_2 emissions, given that they have not been offset, nor will they be offset in the foreseeable future, by carbon capture and storage (CCS) schemes and/or large-scale development of nuclear power.

3.4 Renewable low-carbon energy

The costs of renewable energy have come down considerably since 2007. The Department for Business, Energy and Industrial Strategy (BEIS) now accepts that large-scale onshore wind electricity generation schemes produce electricity at lower cost (£62/MWh) than even gas turbines (£66/MWh), formerly considered the cheapest form of electricity generation.

The 2007 white paper recognised the danger of inaction on anthropogenic global warming (AGW; citing Lord Stern's report of the previous year), and the need for carbon emissions reductions via, *inter alia*, carbon capture and storage (CSS) to offset the burning of fossil fuels. The paper promoted nuclear energy as "one of the currently more cost effective low carbon options". But whereas Lord Stern's warning is ever more true a decade on, the white paper's optimism about CSS helping to offset CO_2 emissions, and the supposed cost-effectiveness of nuclear power, have both proved to be misplaced.

3.5 Discussion

Planning practice guidance for onshore oil and gas (July 2013), quoted in the MLP guidance notes at para. 3.187 states that:

"*Unconventional hydrocarbons are emerging as a form of energy supply, and there is a pressing need to establish – through exploratory drilling - whether or not there are sufficient recoverable quantities of unconventional hydrocarbons present to facilitate economically viable full scale production.*"

This two-part assertion is unfounded: on the contrary: the only pressing need in energy supply is to promote and establish low-carbon forms of fuel, while simultaneously decarbonising the UK economy by the development of carbon capture and storage (CCS). The pressing need for CCS was cogently made by the parliamentary advisory group on CCS last year (the Oxburgh report to BEIS of September 2016).

Nor can it be agreed that unconventional hydrocarbons (discussed in the following sections here) are an "emerging" form of energy supply; on the contrary, they are a declining and slowly dying form of energy supply, as I argue below, and there is no rational or economic need - pressing or otherwise - for the UK to encourage or advance such a form of continued reliance on fossil fuels.

National planning policy guidance states that:

> "*Hydrocarbons remain an important part of the UK's energy mix whilst the country transitions to low carbon energy supplies.*"

This argument is valid, although trite and self-evident; it is indeed impracticable for the 23 million UK households that depend on gas central heating, or for the vast majority of UK motor traffic, to abruptly cease using oil and gas. But the gradual weaning off of fossil fuels required, perhaps over two decades, is not a valid justification for encouraging or even permitting the growth of a new form of expensive and polluting form of fossil fuel energy - unconventionals. The timescale for such a putative development is in any case far too long, and the financial investments and risks are too great. I illustrate this with a few examples.

The UK Onshore Oil and Gas group (UKOOG) envisages 100 drilling pads, each with 40 horizontal (lateral) wells, in a full-scale UK unconventional industry. But for drilling and completing one well it estimates, in production mode:

> "*- a few weeks to prepare the site*
> *- eight to twelve weeks to drill the well*
> *- one to three months of completion activities including between one and seven days of stimulation.*"

UKOOG then concludes:

> "*This initial three- to five-month investment has the potential to deliver a well that will produce oil or natural gas for 20 to 40 years, or more*."

The quotations above, from the current UKOOG website, are identical to those to be found in its pdf handbook dating from October 2013. The time quoted above to drill one well seems to be too slow compared to US drilling times by between 4 and 7 times. However, even using the faster US figures, the drilling and completion time for 40 wells on just one pad, drilled by one high-tonnage rig (capital cost $40M) will be around three years. Completion, using a 'spread' of up to 50 vehicles and employing 90-100 skilled personnel, is a small fraction (perhaps 10%) of this duration, but the capital cost of the

spread is of the order of $50M. Such equipment cannot simply be mobilised from the USA, because the American articulated vehicles are too big (in width and turning circle) to conform to UK roads. The hardware will have to be developed from scratch in Europe or the UK. In short, the development of a fully-fledged UK unconventional hydrocarbon industry will be too slow and cost too much. It should not be encouraged.

The financial risks of trying to kick-start such an industry were discussed in section 3.2 above. UKOOG's estimate that its specimen well would produce for "20 to 40 years, or more" is absurd, given the actual history of the rapid production decline of US wells.

Unconventional fossil fuel (UFF) development was initially designed to break even at an oil price of around $80.The current break-even price of UFF is of the order of $60 per barrel of oil (or gas equivalent) in the best (i.e. most cost-effective) US unconventional play, the Permian Basin. The current price of benchmark West Texas Intermediate (WTI) crude oil is around $50. It has been as low as $30. So even the best of a bad lot (as a respected US oil commentator, Art Berman, describes the Permian play) is losing money. It is accepted by UKOOG and others that the cost of producing UFF in the UK will be far higher than in the US, perhaps even double.

In conclusion, the energy landscape has changed so radically since 2007 that little or no reliance should be placed on that white paper for either national or local policy. Therefore the MLP would be justified in ignoring that aspect of national policy. The economics and the required timescales are also against the development of an indigenous UFF industry.

4 The definition of conventional and unconventional hydrocarbon resources

4.1 National planning practice guidance

The terms 'conventional' and 'unconventional' hydrocarbons are defined in the Minerals Background Paper no. 2 at paras. 4.24 - 4.26. The source of the definitions is not explicitly stated, but it can reasonably be assumed that the definitions are taken from national planning practice guidance. The Minerals section of Planning Practice Guidance, published on 17 October 2014, stateMinerals sections:

> "*Conventional hydrocarbons are oil and gas where the reservoir is sandstone or limestone. Unconventional hydrocarbons refers to oil and gas which comes from sources such as shale or coal seams which act as the reservoirs.*"

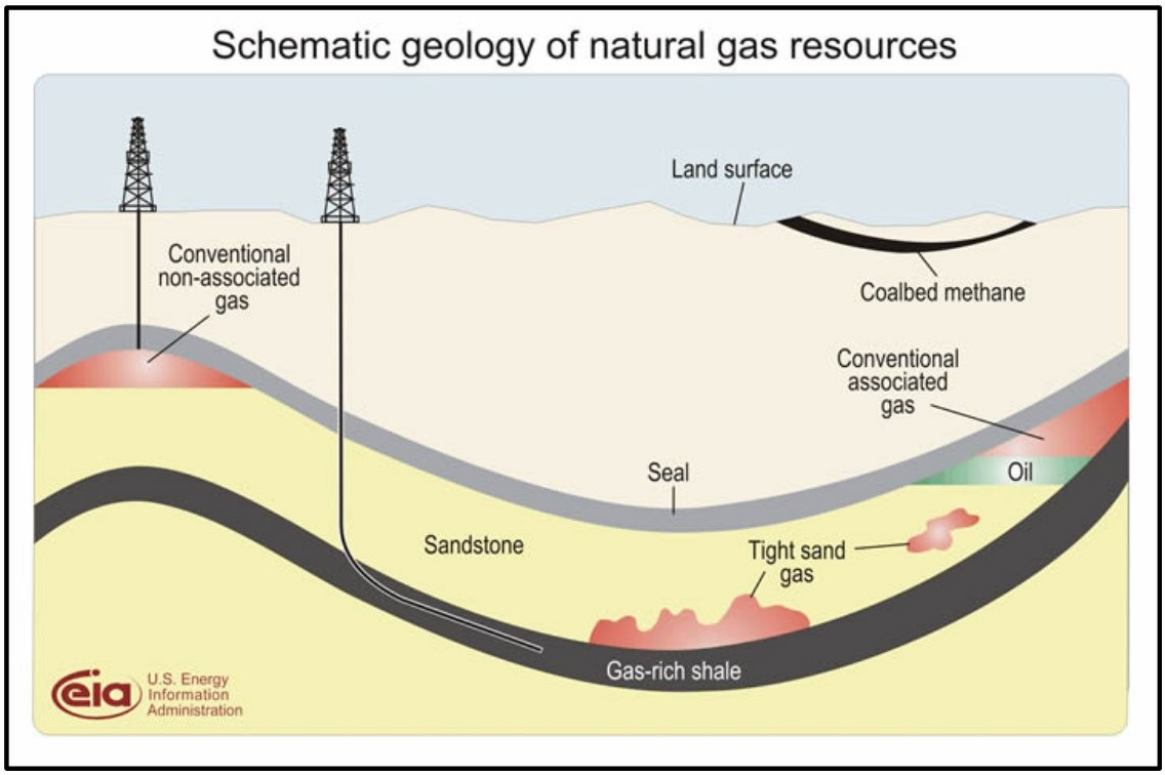
This attempt to define the difference between conventional and unconventional hydrocarbons conflates the mineral itself ("*hydrocarbons*") with the process ("*comes from*") and the supposed source or reservoir rock. But the difference between the two terms is fundamentally one of resource extraction method. The guidance fails to recognise this point.

The definition is unsound for the following reasons:

> 1. It uses overly-simplistic rock types to differentiate between the two resources - "*sandstone*", "*limestone*", "*shale*", "*coal seams*" - without defining them properly. Such nomenclature is too black and white; in practice, there are gradations between end-member rock types; for example, geologists can describe a muddy

sandstone, a sandy limestone, or a sand-prone shale. The end-members themselves, for example, 100% pure limestone, are rather rare in nature.

2. There is no mention of the geological context within which any of these rock types occur, for example, basin position, trap geometry, layer thickness, etc., nor the source where the hydrocarbons have been generated.



Schematic geology of gas resources, from US Energy Information Administration.

3. There is no mention of the physical properties of the rock types, such as permeability and porosity.

4. It omits mention of the physical and chemical properties of the "*hydrocarbons*" themselves, e.g. viscosity, API gravity (oil), or alkane (gas).

5. It omits to mention the processes by which the hydrocarbon is extracted, in particular the difference between hydrocarbons which are extracted from the rock with little or no treatment, *versus* those requiring extensive treatment to make them flow - e.g. steam heating, acidising, or hydraulic fracturing, or whatever forms of reservoir stimulation.

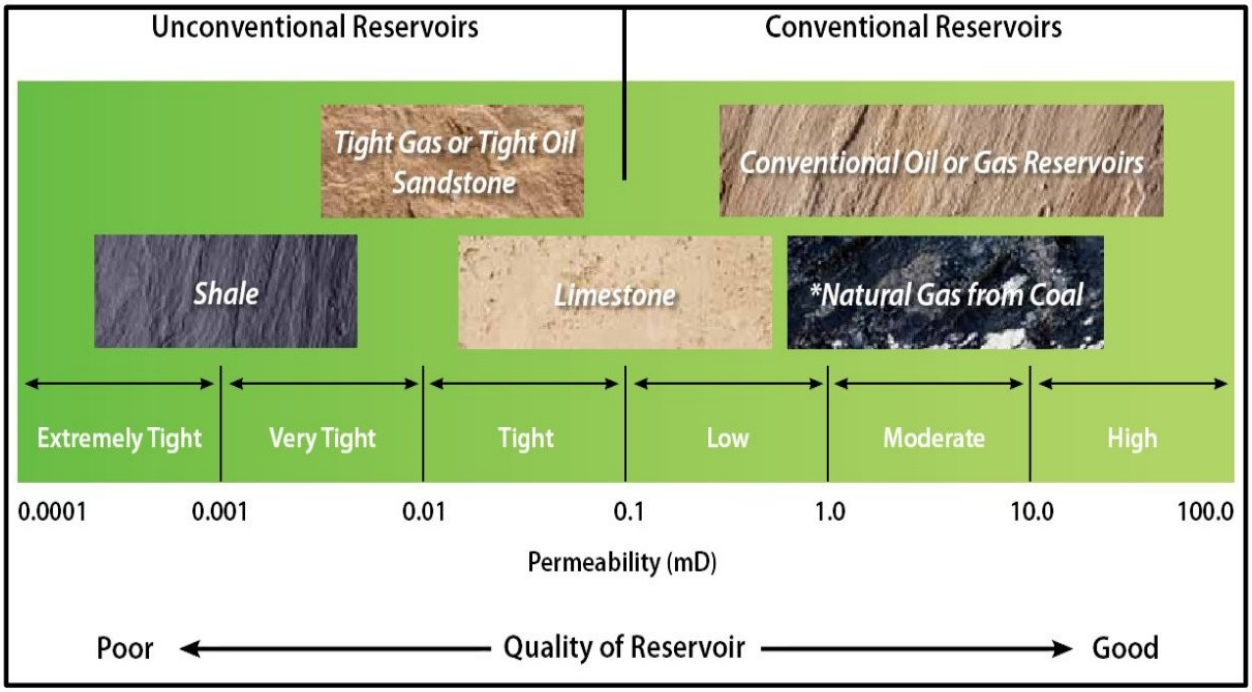
6. There is no mention of the economic aspects of the production process.

I have written to the Department of Communities and Local Government asking for the information to justify its definition, but await a reply.

4.2 Other definitions

There is no universally agreed definition of the difference between conventional and unconventional hydrocarbon mineral extraction; various versions in the scientific and technical literature (see section 7 below) emphasize different aspects mentioned in points 1-6 above. However, all reasonable definitions that I am aware of include, either implicitly or explicitly, the permeability of the host rock.

The figure of 0.1 mD (milliDarcies) for the host rock is generally agreed to differentiate between the two extraction procedures, although the Society for Petroleum and Coal Science and Technology of Germany defines a higher value of 0.6 mD. Given the vast range of possible permeabilities and the limited precision in estimating permeability, the scale is usually presented in logarithmic form, so that units (decades) on the scale are 0.001, 0.01, 0.1, 1, 10 ... mD and so on. Below 0.1 mD the process required to extract the hydrocarbons is unconventional, whereas above that value it is considered to be conventional.



Spectrum of permeabilities to differentiate between unconventional and conventional reservoirs (Canadian Society for Unconventional Resources).

Next in importance to a quantitative definition using permeability comes the geological setting in which the hydrocarbon-bearing rock occurs. Thus conventional resources are found in finite and well-defined traps, whereas unconventional gas or oil is distributed throughout a widespread layer with no clear-cut boundaries.

Along with the two criteria above, the process of extracting the hydrocarbons is important. It is variously described as fracking, acidising, massive stimulation, additional extraction or conversion technology, or assertive recovery solution. Although different in detail, what they all have in common is the aim of making the hydrocarbon flow when it would otherwise not do so.

4.3 Discussion and conclusion

No definitions of which I am aware (see list below) regard so-called "*sandstone*" or "*limestone*" reservoirs as automatically conventional, as simplistically defined by the national planning practice guidance. On the contrary, many sandstone and limestone reservoirs are called 'tight', meaning that unconventional extraction methods are required.

Given the unscientific and imprecise nature of the definition, it would be justifiable for the MLP to ignore it as being unsound.

5 Definition of hydraulic fracturing

5.1 Introduction

Footnote 22 to para. 3.185 of the Background Document quotes section 4B of Section 50 of the Infrastructure Act 2015. This section, which defines hydraulic fracturing ('fracking'), is as follows:

> ***"Section 4A: supplementary provision***
> *(1) "Associated hydraulic fracturing" means hydraulic fracturing of shale or strata encased in shale which—*
> *(a) is carried out in connection with the use of the relevant well to search or bore for or get petroleum, and*
> *(b) involves, or is expected to involve, the injection of—*
> *(i) more than 1,000 cubic metres of fluid at each stage, or expected stage, of the hydraulic fracturing, or*
> *(ii) more than 10,000 cubic metres of fluid in total."*

5.2 Weaknesses in the wording of the definition

There are two intrinsic weaknesses in the wording of this definition:

Weakness 1: "*shale or strata encased in shale*", and
Weakness 2: the word "*expected*" (quoted twice).

The first weakness is that the phrase in question is almost meaningless. Does it mean that the strata referred to which are not composed of shale, have to lie in direct contact with shale, above, below and all round on all sides? The phrase is unclear. In practice, almost any layer within a sedimentary basin is likely to be 'encased in' shale, excluding the very bottom layer resting on 'basement' rock, and excluding the uppermost layer at the surface of the earth. This is because shale is a very common variety of sedimentary rock, and there are likely to exist layers of shale above and below the stratum in question.

The second weakness, the expectation of a specified threshold volume of fluid, implies a belief that a certain amount will or will not be used. 'Expectation' is not being used in the statistical sense of the word, because the definition refers to discrete operations, occurring one at a time, and not to an aggregate of simultaneous and unpredictable operations for which statistical methods might be appropriate. The questions arise; who is doing the 'believing'?

What happens if the expectation that less than the specified amount turns out to be incorrect? The process of hydraulic fracturing involves the insertion of fluid into rock at

depth. The volume being inserted is both continuously monitored and controlled by the operator at the surface. Now it may be the case during any one fracking stage, for which planning approval has been granted on the basis that the process will *not* fall under the definition of associated hydraulic fracturing of shale, that the operator may decide, based upon the perceived progress of the fluid pressure and volume, to insert a greater volume than specified by the threshold. That action implies that the planning consent has been wilfully breached. The alternative, which is under the complete control of the operator, is merely to turn off the fluid supply valve before the threshold is exceeded. This freedom of action applies both for any one stage and for the n'th stage at which the total threshold is in danger of being breached.

In conclusion, I can see no justification for someone's belief to be inserted here as part of a legal definition. It implies a discretion on the part of the operator, of whether or not to abide by the planning consent. Such a weak phrasing of the definition may therefore be open to challenge.

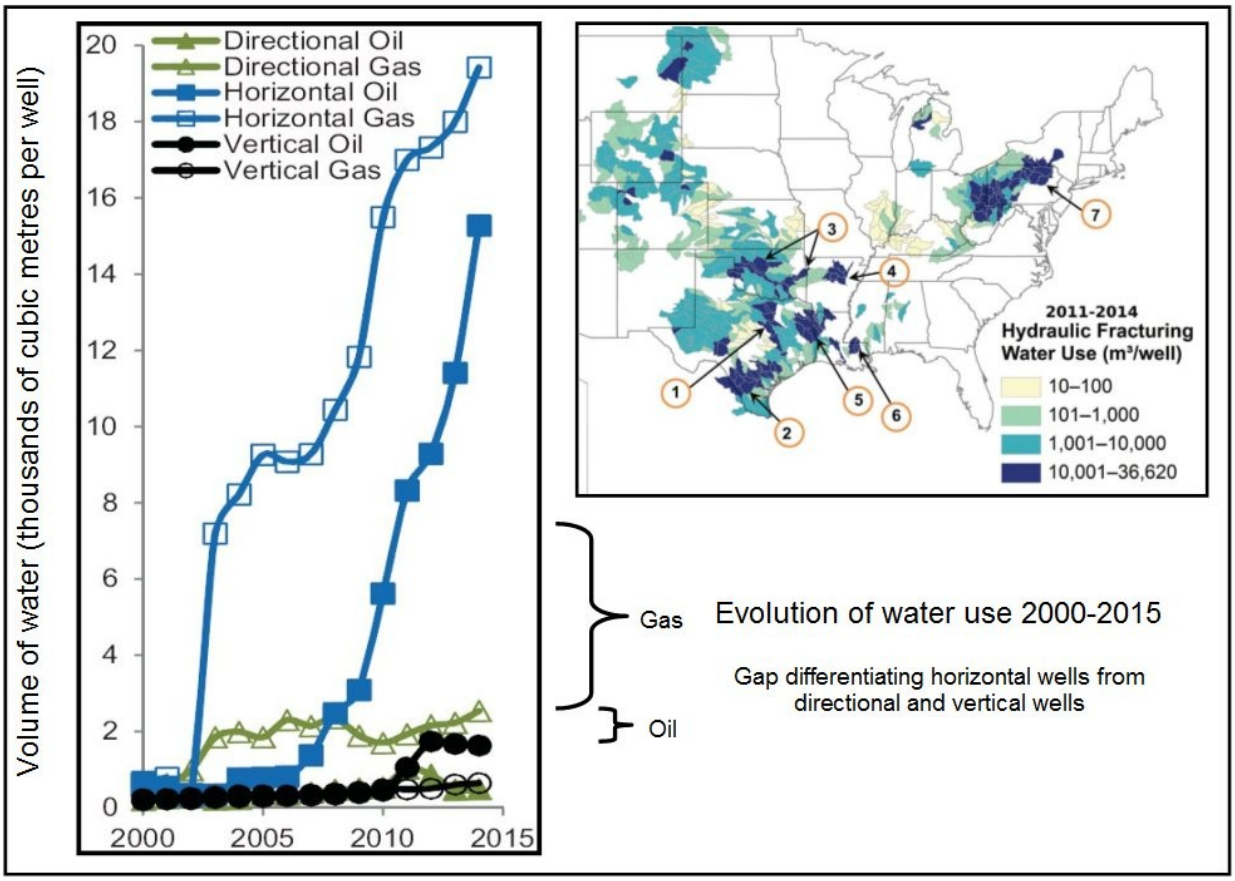
5.3 The use of fluid volume as a criterion

The definition involves the specification of two alternative minimum fluid volume measures, without qualification. It follows the definition of the European Commission (EC) published in the Official Journal of the European Union dated 8 February 2014. This in turn seems to be based on a consultant's report to the EC by AEA dated August 2012, proposing a figure of 1000 cubic metres for each fracking stage. There is little justification in this report for such a figure, and in any case the scanty research upon which it is based, comprising merely a literature review, has been superseded by the thorough US Geological Survey (USGS) continent-wide study discussed below.

Two questions arise from this definition; (a) whether fracking can be soundly defined by such a criterion, and (b) even if this be the case, whether the quoted threshold values are based on sound evidence.

Dr Stuart Gilfillan and Professor Stuart Haszeldine, shale gas researchers at the University of Edinburgh, raised both these questions in an article published in April 2016. They quoted an extensive data compilation from the US Geological Survey (USGS) involving over a quarter of a million fracked oil and gas wells. Because the wells have been fracked, they are, using any reasonable definitions (discussed in section 4 above), unconventional.

The USGS data are treated statistically, with yearly or other medians being calculated. The type of well falls into three categories; vertical (V), directional (D) or horizontal (H). There are two UFF types distinguished - oil (O) or gas (G). The yearly medians for the six resulting categories, estimated from 2000 to 2014 inclusive (15 years in total, but the data being incomplete for 2015), show a very pronounced bimodal distribution, separating horizontal wells H with large water volume use from directional D or vertical wells V with lesser water volume use. The authors argue on geographical grounds that the horizontal wells, by and large, represent shale plays rather than tight sandstone or limestone plays.



US study of 264,000 fracked wells. Graph shows the range of values which differentiate between horizontal wells (high volume usage) and deviated or vertical wells (low volume usage), for oil and for gas separately. Shale gas plays are numbered in the map: (1) Barnett, (2) Eagle Ford, (3) Woodford, (4) Fayetteville, (5) Haynesville-Bossier, (6) Tuscaloosa, and (7) Marcellus and Utica.

For simplicity in the following summary the directional and the vertical categories are grouped together as DV.

H wells of both resource types show an annual evolution towards greater and greater water use, up to and including 2015. DV wells reveal a slight growth in water use, but flattening out over time.

For gas wells, the annual median values of water volume (in cubic metres per well) that separate horizontal H from deviated/vertical DV wells are as follows:

DV ≤ 2537, in 2015; H ≥ 7192, in 2003
(≤ means 'less than or equal to; ≥ means 'greater than or equal to').

In other words, any value between 2500 and 7000 cubic metres could serve as the threshold criterion for differentiating between H shale well water volume use and other tight rock, drilled by DV wells.

For oil wells the separating figures are:

DV ≤ 1740, in 2012; H ≥ 2479, in 2008.

So a round figure of 2000 cubic metres could be used as the threshold figure.

The figures quoted here are medians for water use per well. The secular increase in water use in horizontal wells is ascribed to evolving drilling and fracking techniques; for example, wells are generally much longer now than a decade ago. There are significant differences in the mean water use between shale plays, reflecting, in part, different physical properties of the shale.

The results suggest firstly that the figure of 10,000 cubic metres chosen in the Infrastructure Act definition is too large by a factor of at least four. Secondly, the utility of having such a definition in the first place could be considered unsound. As the USGS authors conclude:

> "*Because hydraulic fracturing is not a one-size-fits-all operation, assumptions and generalizations regarding water use in hydraulic fracturing operations and the potential for environmental impacts should be made with caution*."

The Edinburgh researchers suggest that strain rate may prove to be a better criterion than simply fluid volume; this is a measure of how fast the rock cracks up when fracked, and involves the applied fluid pressure and the rate of flow, as well as the total volume. But they question why such a definition is needed at all.

I therefore submit that the attempt to define hydraulic fracturing by any minimum threshold volume criterion is unsound. In addition, the volume figures selected as discrimination criteria are contrary to established evidence, by being far too high, and the wording of the definition itself has weaknesses which render it unsound in a legal sense. Fracking remains fracking if it artificially enhances permeability in rock, whether the method used is (a) fluid under high pressure or (b) dissolution by acids. Fracking type (a) is hydraulic fracturing; fracking type (b) is chemical fracturing. Both types of permeability enhancement fall under the umbrella of 'unconventional' fossil fuel exploitation.

In conclusion, the definition, being both legally and scientifically unfounded, should not play any part in the MLP.

6 Conclusions

There are no compelling economic arguments for developing unconventional fossil fuels in the UK; on the contrary, the US financial experience should serve as a warning. An indigenous unconventional fossil fuel (UFF) industry can never be a 'transitional' energy source because it will clearly take too long to develop. The cost of indigenous UFF will be so much higher than in the US that any such industry would require heavy subsidy, and/or penalise the consumer by the application of severe import tariffs, or even import bans.

National security of supply is not an argument that should carry any weight in a MLP. It is evident that with the current glut of natural gas and oil, imports from historically reliable exporting countries such as Qatar, Norway and the USA can continue as before.

The definitions and assumptions behind the national planning policy on UFF and on fracking are so unsound that it would be rational for the MLP to ignore them, and to

conclude, taking into consideration the other evidence I have offered, that UFF - however defined - is not to be welcomed in West Sussex.

On the other hand, I accept that onshore conventional fossil fuel (CFF) development may have a continuing (but minor future) in the UK, and it is correct to say that there have been almost no cases of environmental damage at the exploration or production sites resulting from such activity. But that is not to say that CFF is to be encouraged in the future, unless and until CSS is in place to offset the CO_2 produced by the consumer in burning such fuel.

7 Notes, references and links to definitions of unconventional resources

Schlumberger (major oil services supplier): refers to exploration scale and frequency, economics, porosity and permeability.

Petrowiki (published by Society of Petroleum Engineers, SPE): unconventionals cannot be produced at economic flow rates without assistance of massive stimulation treatments.

Halliburton (major oil services supplier): unconventional reservoirs require assertive recovery solutions.

Canadian Society for Unconventional Resources (CSUR pdf slideshow): slide 7 shows the 0.1 mD divide between unconventional and conventional.

US Department of Energy (DOE): unconventional resources depend on the state of the hydrocarbon, nature of the geologic reservoirs and the types of technologies required to extract the hydrocarbon. Conventional oil and gas deposits have a well-defined areal extent, the reservoirs are porous and permeable, the hydrocarbon is produced easily through a wellbore, and reservoirs generally do not require extensive well stimulation to produce. Unconventional hydrocarbon deposits are very diverse and difficult to characterize overall, but in general are often lower in resource concentration, dispersed over large areas, and require well stimulation or additional extraction or conversion technology.

US Energy Information Administration (EIA) glossary: produced by means that do not meet the criteria for conventional production, which is defined as crude oil and natural gas that is produced by a well drilled into a geologic formation in which the reservoir and fluid characteristics permit the oil and natural gas to readily flow to the wellbore.

Harris Cander, BP, presentation to American Associaton of Petroleum Geologists (AAPG), 2012: simple definition by BP geologist using both porosity and permeability, with the latter set at 0.1 mD for low porosities.

UK Onshore Oil & Gas (industry trade group): key difference between unconventional and conventional - stimulation required before the hydrocarbon will begin to flow.

Oil & Gas Journal (leading US industry magazine): tight reservoirs require large hydraulic fracture treatment and/or are produced using horizontal wellbores.

Michael Stephenson (Chief Scientist, British Geological Survey) non-technical book *Shale gas and fracking* (Elsevier, 2015), pp 32-33: conventional is a natural system that

creates and stores hydrocarbons in limestone or sandstone traps; with unconventional, the shale has not released its gas, so fracking is required. No mention of tight hydrocarbons.

EU research documents prepared for the European Commission: AEA 2012, AMEC 2015, 2016: criteria for distinguishing between CFF and UFF include:

- permeability,
- geological environment,
- discrete vs. gradational boundaries,
- techniques for drilling and stimulation.

AEA 2012. Support to the identification of potential risks for the environment and human health arising from hydrocarbons operations involving hydraulic fracturing in Europe Report for European Commission DG Environment.

Amec Foster Wheeler Environment & Infrastructure UK Limited (AMEC) 2015. Technical Support for the Risk Management of Unconventional Hydrocarbon Extraction Final Report. European Commission DG Environment.

Amec Foster Wheeler Environment & Infrastructure UK Limited (AMEC) 2016. Study on the assessment and management of environmental impacts and risks resulting from the exploration and production of hydrocarbons Final Report. European Commission.

Gallegos, T. J., B. A. Varela, S. S. Haines, and M. A. Engle 2015. Hydraulic fracturing water use variability in the United States and potential environmental implications, *Water Resour. Res*., 51, 5839–5845, doi:10.1002/2015WR017278.

Gilfillan, S. and Haszeldine, S. 2016. What's in a name: The risks from re-defining fracking. Energy and Carbon Blog.