Fracking:

How it works, its application and potential in the UK, its various impacts, and how it may affect the High Weald AONB

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Contents

1. What is shale gas?

Shale gas is simply natural gas – composed of c.90% methane – trapped within shale deposits (Jackson et al., 2011). However, shale gas differs in a number of important ways from "conventional" natural gas.

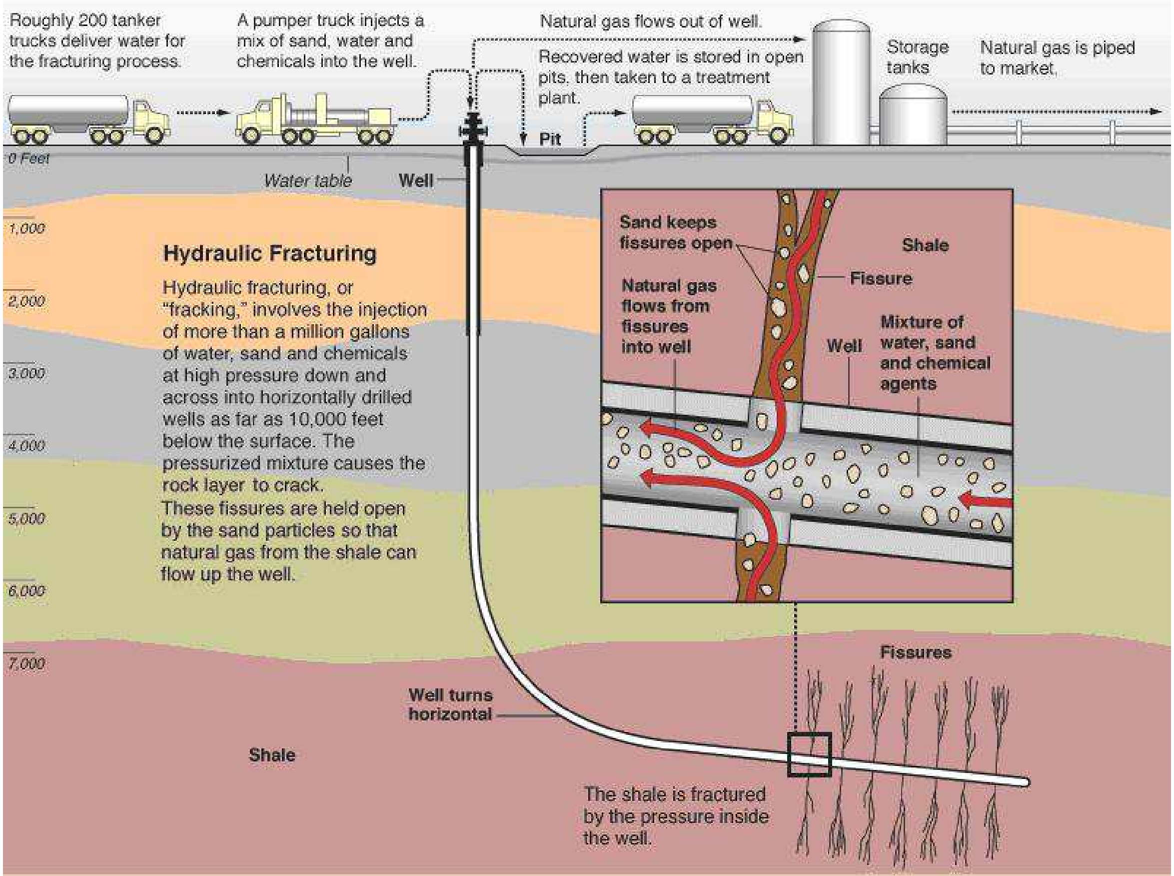
Conventional gas (and oil) refers to hydrocarbon deposits found at relatively shallow depths (usually less than c.1500m) in sandstone or limestone formations, instead of the deeper (usually greater than c.1500m, but sometimes as much as 6000m) shale, tight sands or coal beds which are now the focus of "unconventional" exploration (Andrews, 2013; Energy & Capital, 2013). In conventional oil and gas accumulations, shales comprise the source rock from which hydrocarbons are generated following burial. Through geological time, these hydrocarbons migrate from this shale source rock, through carrier beds and ultimately accumulate in porous reservoirs – typically composed of sandstone or carbonate – in discrete traps (Andrews, 2013). These traps are usually located in structural highs on the margins of basin centres. In the case of unconventional hydrocarbon accumulations, such as shale gas, this logic is turned on its head, with the shales themselves acting as both source and reservoir rock, and the extensive basin centres becoming the exploration targets (Andrews, 2013).

In addition to shale gas, exploration for tight gas (usually found in sandstone, but also occasionally in limestone) and coal bed methane is currently underway in the UK (Andrews, 2013). Like shale gas, both use horizontal drilling and fracture stimulation technology to enhance natural fractures and recover gas from rocks with low permeability (Mooney, 2011; Andrews, 2013). It is only within the last few decades that technology has enabled shale gas – as well as these other types of gas – to be exploited more economically.

2. How is shale gas extracted through fracking?

Hydraulic fracturing involves pumping millions of gallons of fluid into a gas or oil well at high pressure to create fractures in the rock formation. The fractures extend a few hundred metres into the rock and the newly created fractures are propped open by sand added to the fluid. Additional fluids are pumped into the well to maintain the pressure and ensure that fracture development can continue and proppant can be carried deeper into the formation (API 2009; Bickle et al., 2012). Because a well may be too long to maintain sufficient pressure to stimulate fractures across its entire length, plugs may be inserted to divide the well into smaller sections, known as stages. These stages are then fractured sequentially, beginning with the stage furthest away and moving towards the start of the well (Mooney, 2011; Ellsworth, 2013). After fracturing, the plugs are drilled through (in a process known as "drill-out") and the well is depressurised, creating a pressure gradient so that gas flows out of the shale and into the well (Howarth et al., 2011). Fracturing fluid also flows back to the surface ("flowback" water), along with saline/brine water ("formation" water) from deep within the shale formation itself, which, depending on the geology, contains a range of dissolved minerals and naturally occurring radioactive materials (NORMs), such as uranium, radium, radon, and thorium. Fracturing fluid and formation water returns to the surface over the lifetime of the well as it continues to produce shale gas. Although definitions vary, flowback water and formation water collectively constitute "wastewaters" (EPA, 2011a; Bickle et al., 2012).

Figure 1. Illustration of a working fracking operation.



Graphic by Al Granberg (available from: http://www.propublica.org/special/hydraulic-fracturing-national).

3. Additional facts about the fracking process

- The well-pads used for fracking operations in the US typically require the clearance of an area of between 1.5 and 3 hectares, which can then support up to 12 separate wells (Entrekin et al., 2011; Penn State, 2011). In the UK, the well pads planned by Cuadrilla for exploration and production from the Bowland Shale are approximately 0.7ha, and will contain 10 wells (Regeneris Consulting, 2011). It is currently unknown how operations at other UK sites may proceed.
- The horizontal leg of a well is usually divided into a number of sections which are fractured separately during the course of several fracking "events", allowing for up to 15 separate hydrofracks at a single well (Kargbo et al., 2010; Entrekin et al., 2011).
- Fracturing fluid is typically c.95% water, but also contains numerous chemical additives (usually comprising less than 1% of the fluid), as well as propping agents (which make up around 5% of the mixture and are commonly composed of sand), that are used to keep fractures open once they are produced under pressure (Jackson et al., 2011; Bickle et al., 2012; Frac Focus, 2013a). The chemicals added to fracturing fluid include friction reducers, surfactants, gelling agents, scale inhibitors, acids, corrosion inhibitors, antibacterial agents and clay stabilisers (Bickle et al., 2012), the purpose of which is to achieve an ideal viscosity that encourages fracturing of the shale and improves gas flow, but discourages microbial growth and corrosion that can inhibit recovery efficiency (Entrekin et al., 2011).
- Some of these chemicals are known to be highly toxic and/or carcinogenic, and include, for example, hydrochloric acid, boric acid, isopropanol, lead, methanol, ethylene glycol, diesel, and formaldehyde, as well as benzene, toluene, ethylbenzene, and xylene compounds (Entrekin et al., 2011; Jackson et al., 2011). (For a more comprehensive list of chemicals typically used during

hydraulic fracturing, along with their purpose, visit: http://fracfocus.org/chemical-use/what-chemicals-are-used).

- Each frack uses c.8-32 million litres of water (Entrekin et al., 2011; Mooney, 2011; DECC, 2013a; Frac Focus, 2013a; Explore Shale, 2013), which, given the fact that the horizontal leg of a single well can be fracked in discrete sections and even multiple times (Entrekin et al., 2011), means water usage at a single well may exceed 100 million litres of water (although Moore (2012) claims that when these huge numbers are put into perspective, they do not seem so excessive – e.g. c.19 million litres 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).
- Depending on the site, 15-80% of the fracturing fluid injected into the borehole is recovered as "flowback" at the well head. In the US, these "flowback" fluids are often stored in open pits on-site and disposed of through either injection into underground wells, or through transferral to a water treatment facility (Manual, 2010). Such open storage is not normally permitted in the UK; although disposal would likely involve similar techniques (subject to UK laws and regulations, namely the Mining Waste Directive and Water Framework Directive), with some of the flowback water even being reused in subsequent fracking operations following dilution (Bickle et al., 2012; Frac Focus, 2013a).

4. How big are UK shale gas reserves?

Due to the fact that the UK shale gas industry is still in its infancy, there is considerable uncertainty as to the size of the country's shale gas resource. However, recent research by the British Geological Survey, the US Energy Information Administration and the Royal Society, suggest that:

- The Bowland-Hodder shale gas play – which covers a large portion of central and northern Britain and is currently thought to be Britain's most gas-rich shale deposit – may contain as much 2281 trillion cubic feet (tcf), or 64.6 trillion cubic metres (tcm), of "in-place" shale gas (defined as the total volume of gas that exists, rather than the volume which it is technically or economically feasible to extract) (Andrews, 2013). It should be noted that this is an upper estimate, and the British Geological Survey calculate that the resource could be as small as 822 tcf, with a middle estimate of 1329 tcf (Andrews, 2013).
- 19 tcf of the Bowland-Hodder resource has been identified as "technically recoverable" – defined by the US Geological Survey as the proportion of an assessed in-place resource that may be recoverable using current technology, without regard to cost. This may be contrasted with so-called "proved reserves", a term which refers to that volume of technically recoverable gas demonstrated to be economically and legally producible under existing economic and operating conditions (Bickle et al., 2012; USEI, 2011).
- The total size of the UK's technically recoverable shale gas resource is thought to be 20 tcf (Bickle et al., 2012; USEI, 2011), with the Liassic shales of the Wealden basin contributing 1 tcf to the Bowland-Hodder shale's 19 tcf – this represents a significant resource in view of the fact the UK's annual gas consumption is currently about 3 tcf (Smith et al., 2010; Moylan, 2013).

It is worth noting that there is particular uncertainty over the size of the technically recoverable shale gas resource in the Weald. Indeed, the oil and gas exploration company, Celtique Energie, estimate that the Wealden basin may contain as much as 14 tcf – as well as 125 million barrels of shale oil (British Geological Survey, 2012). A study of the Jurassic shales of the Weald Basin commissioned by the Department for Energy and Climate Change (hereafter DECC), and conducted by the British Geological Survey, will be available later this year, and should provide greater clarity on this issue (Andrews, 2013).

5. What is the history of fracking in the UK?

Over the last 30 years, more than 2,000 wells have been drilled onshore in the UK, approximately 200 (10%) of which have been hydraulically fractured to enhance recovery (Bickle et al., 2012). The combination of hydraulic fracturing and directional drilling allowed the development of Wytch Farm in Dorset in 1979. Discovered by British Gas in the 1970s and operated by British Petroleum since 1984, the field is responsible for the majority of UK onshore oil production (over 200 wells have been drilled) and is Europe's largest onshore oil field (British Geological Survey, 2012; Bickles et al., 2013). In 1996, British Gas hydraulically fractured a well in the Elswick Gas field in Lancashire – 4.5km from Cuadrilla's Preese Hall well – and gas has been produced from it ever since.

It was not until the mid-1980s that research began into the potential for gas production from UK shales. In 2003, the Petroleum Revenue Act was repealed, exempting shale gas production from the Petroleum Revenue Tax (Selley 2012). In 2008, 97 Petroleum Exploration and Development Licences were awarded for shale gas exploration in the UK during the 13th Round of Onshore Licensing, with the 14th licensing round still pending following the seismic tremors encountered during fracking operations at Cuadrilla's Preese Hall site in Lancashire (Bickle et al., 2012; DECC, 2013b).

Although fracking techniques were not employed, it is of local historical interest that one of the country's first natural gas deposits was found at the entrance to Heathfield tunnel, to the north of the railway station, in 1895. The find was not exploited until the following year when the railway company began drilling for water and gas at a depth of 312 feet. The railway quickly put the gas to good use by illuminating the station. In 1901 a group of Americans, under the name of 'The Natural Gas Fields of England Ltd.' sank further bore holes. The output of one of these was recorded at 15 million cubic feet a day – equivalent, at the time, to one eighth of the total daily sale of gas in London. By 1934 the gas supply was much reduced and the station lighting was converted to use ordinary town (i.e. coal-derived) gas (Catford, 2010; Heathfield Town, 2013). However, at the behest of the then Ministry of Mines, gas from Heathfield was being compressed into cylinders to be sent away for research purposes until 1963, when supplies began to fail and the hole was sealed off.

6. What is the current state of shale gas exploitation in the UK in general and the High Weald in particular?

Fracking for shale gas is still very much in its infancy in the UK, although there have been some notable developments – particularly since the ban on fracking was lifted at the end of 2012 (DECC, 2012a):

- Five potential shale gas exploration well sites have been identified by Cuadrilla in Lancashire. The first test well was drilled in August 2010 at Preese Hall, a second at Grange Hill Farm later that year and a third near the village of Banks in August 2011. Hydraulic fracturing has been undertaken at Preese Hall only (Bickle et al., 2012).
- Three possible sites have been identified in the Mendip Hills by UK Methane and Eden Energy and planning permission has been sought for boreholes for geological samples; although UK Methane has stated it has no interest in hydraulic fracturing at this stage (Bickle et al., 2012).
- A site has also been identified in Woodnesborough, Kent, by Coastal Oil and Gas Ltd. (also known as UK Onshore Gas Ltd.). Planning permission for a temporary change of use from agricultural land, as well as permission for exploratory drilling, was granted in 2011, although no drilling has yet taken place (KCC, 2010a; Stott, 2013).
- In terms of the High Weald AONB, the only sites for which the DECC has granted licenses for exploratory drilling are in Cowden, Kent and Balcombe, West Sussex. Both these sites are owned and operated by the energy company Cuadrilla, and in both cases permission has been granted for exploration only – hydraulic fracturing would not be able to take place unless the company applies

for, and receives, further permission from the DECC (KCC, 2010b; WSCC, 2010; Energy Global, 2013). In relation to Cowden, Cuadrilla states on its website that “there is no intention at the current time to carry out any additional work at Cowden in Kent following some initial evaluation in 2010 of the well”. In terms of Balcombe, Caudrilla says that, since beginning on the 2nd of August 2013, test drilling is ongoing. For more information on these and other Cuadrilla sites, visit: http://www.cuadrillaresources.com/our-sites/.

7. What are the environmental and public health concerns associated with fracking?

7.1 Earthquakes

- Micro-earthquakes – i.e. those below a magnitude of two – are routinely produced as part of the hydraulic fracturing process (Ellsworth, 2013). Such earthquakes are generally not felt by people, but can be detected by local seismographs (Environment Canterbury, 2011; British Geological Survey, 2013a; US Geological Survey, 2013).
- The two seismic events that occurred near Blackpool in 2011 (a 2.3M earthquake on April 1st and a 1.5M earthquake on May 27th) have been attributed directly to fluid injection during hydraulic fracturing by both the drilling company involved (Caudrilla) and an independent government report (Bickle et al., 2012; Green et al., 2012).
- However, the process, as currently practiced, appears to pose a fairly low risk of inducing destructive earthquakes; in recent years in the US more than 100,000 wells have been subject to fracking, with the largest induced earthquake being a magnitude 3.6 – too small to cause serious damage (Ellsworth, 2013).
- It seems wastewater disposal by injection into deep wells poses a higher risk because it is capable of inducing larger earthquakes (DECC, 2013a; Ellsworth, 2013). Indeed, a 5.6M event in Oklahoma that destroyed 14 homes and injured two people is thought to have been caused by the injection of large volumes of water into a disposal well near to a basement fault (Ellsworth, 2013).
- However, a recent by study Frohlich and Brunt (2013) suggests that, under certain geologic conditions, the extraction of fluids – i.e. the extraction of shale oil and naturally occurring brine during fracking – can cause more earthquakes (documented up to Magnitude 4.8) than the injection of wastewater into deep wells. Therefore, to more fully understand the potential earthquake risk from fracking activity in the Weald, a detailed knowledge of the region’s subsurface geology and fault structure – as well as the volume of fluid that is likely to be extracted, the volume of fluid that is likely to be disposed of through deep injection, and the proximity of this extraction and injection activity in relation to pre-existing geologic faults – is required.

7.2 Ground and surface water contamination

- Due to the large volume of wastewater (a combination of flowback water and formation water) produced during the lifetime of a well, and the fact that this water contains a significant quantity of chemicals that are hazardous to the environment and to human health, there is considerable concern about water contamination.
- In terms of surface water contamination, the primary risks are: accidental spills, inadequate treatment practices for recovered wastewaters, and elevated sediment runoff into streams as a result of vegetation clearance and stream disturbance during well and infrastructure development (Willams et al., 2008; Entrekin et al., 2011).
- In theory, the risk of surface water contamination from fracking operations in the UK should be less than in the US, due to the fact that wastewater in the UK must be stored in closed metal tanks before being treated/disposed of, rather than in open storage ponds (Bickel et al., 2012). However, the management, disposal and/or reuse of fracking wastewater is complex, and, as with many industrial processes, leaks and spills are an ever-present risk.

- In terms of groundwater contamination, the primary risks are: contamination via chemical leakage during fracking operations themselves, chemical leakage during the disposal of wastewater via injection into deep wells and the migration of methane into overlying groundwater through fracking-induced fissures (Holzman, 2011; Jackson et al., 2011; Osborn et al., 2011).
- As yet there is no peer-reviewed evidence for the contamination of groundwater by chemicals from fracking fluid, and, if done properly, it is generally considered that fracking operations are conducted at depths sufficient to make groundwater contamination very unlikely (Bickle et al., 2012). However, groundwater contamination is certainly possible due to well-failure/leakages, downward percolation from surface spills, or if UK fracking operations occur at shallower depths – and thus closer to groundwater stores – than in the they do in the US (something which will not be known for certain until further research and exploration of UK shale deposits occurs). Bishop (2011) estimates a groundwater pollution rate by fracking fluids of 2% for the natural gas industry in New York State since 1979.
- The disposal of fracking wastewater in the UK would be regulated under the Mining Waste Directive and the Water Framework Directive. However, the proportion of fracking wastewater in the UK that would be disposed of by injection into deep wells is currently unknown and will depend on a variety of factors, such as: the chemicals used in fracking fluids, the availability of appropriate treatment facilities and the proportion of water that can be reused. Ultimately, if the disposal of fracking wastewater is done properly, the risk of groundwater contamination is likely to be fairly low (Bickle et al., 2012).
- It should be noted that the risk of groundwater contamination may increase over the entire lifecycle of a well, whether this be an abandoned fracking well, or a wastewater disposal well. Indeed, research shows that at timescales of greater than 50 years, due to concrete shrinkage causing fissures in the well casing, well casing failure can occur (Bishop, 2011; Dusseault et al., 2000). Cracking becomes especially severe at maximum depth, where the exposure of concrete casings to the hot (140 –180 °F) brines accelerate their breakdown, permitting subterranean gases and other fluids to re-pressurize the deteriorating well and thus help force gas upwards, potentially into overlying aquifers (Desseault et al. (2000) report that in North America “tens of thousands” of abandoned and inactive – as well as active – oil and gas wells currently leak gas to the surface, with some of this gas entering shallow aquifers, causing water to become unpalatable and homes unsafe). It would be of particular concern if the same processes were to force fracking wastewater back towards the surface and, ultimately, through cracks in well casing and into groundwater. There is currently no evidence for this, but it should be noted that fracking for shale gas on a large-scale is a relatively recent development and that, as stated above, such contamination – if it were to occur – would likely take 50 years to become apparent. Therefore, long-term monitoring of abandoned wells would need to be undertaken before this potential danger could be ruled out.
- The danger of post-abandonment groundwater contamination may be of concern given the UK’s current regulatory framework. Although operators are required to submit an abandonment plan and obtain permission before commencing amendment (as well as being required to design, construct and operate wells in such a way that they can be suspended or abandoned at any time in a safe manner, with no subsequent unplanned fluid escape (Schoenmakers, 2009)), unless there is an “unusual or adverse development” during the abandonment process, no subsequent monitoring is required (Bickle et al., 2011). Therefore, it is possible that a well could be abandoned and, as long as the process of abandonment itself occurs without incident, any future leakage or contamination could go undetected. It should be noted, however, that the need for post-abandonment monitoring was highlighted by a Royal Society and Royal Academy of Engineering report into the risks associated with fracking (Bickle et al., 2012), and that the government has subsequently acknowledged these recommendations. Their response stated that DECC will work with the United Kingdom Onshore Operators Group (the representative body for the UK onshore oil and gas industry) to “put in place a robust scheme to ensure abandoned wells remain safe and which satisfies, and is incorporated within, site restoration and remediation agreements under the planning process” (DECC, 2012b p.2).

- Unlike contamination by wastewater, it appears there is strong evidence that fracking activity can lead directly to increased concentrations of methane in groundwater (Holzman, 2011; Jackson et al., 2011; Osborne et al., 2011).
- Osborne et al. (2011, p.8172) found that "in active gas-extraction areas (one or more gas wells within 1 km), average and maximum methane concentrations in drinking-water wells increased with proximity to the nearest gas well and were 19.2 and 64 mg CH4 L^{-1} (n=26), a potential explosion hazard; in contrast, dissolved methane samples in neighbouring non-extraction sites (no gas wells within 1 km) within similar geologic formations and hydro-geologic regimes averaged only 1.1 mg L^{-1}."
- Although dissolved methane in drinking water is not currently seen as a health hazard for ingestion (more research is needed to investigate this, as its long-term health effects are poorly understood), it is an asphyxiant in enclosed spaces and an explosion and fire hazard.
- The British Geological Survey is currently undertaking a national survey to establish baseline concentrations of methane in groundwater across the UK, as well as gathering data on a range of other parameters and chemicals. Areas already sampled include sites in East Sussex, West Sussex and Kent (British Geological Survey, 2013b).

7.3 Traffic, noise, pollution and general disruption associated with site setup and operation

- Disruptive activities include the construction of roads for the transport of heavy equipment, such as the drill rig, the levelling of the site, the erection of structures for erosion control, the excavation of pits/instillation of tanks to hold drilling fluids and drill cuttings, and the placement of racks to hold the drill pipe and casing strings (Frac Focus, 2013b).
- During the development of a site and hydraulic fracturing job, there will be an increase in heavy traffic on the roads surrounding the site as equipment, such as the drill rig, bulldozers, graders, water trucks (about 200 tanker trucks of water are required for a single frack (ProPublica, 2013)) and other heavy equipment, is transported to and from the site.
- This traffic increase usually lasts a few weeks and, once well drilling, completion and fracturing are finished, should decrease substantially (Frac Focus, 2013b).
- However, the ecological damage caused by this increase in traffic and hence vehicle emissions – particularly if this fracking traffic passes near to an ecologically sensitive site – could be significant (Corney et al., 2008). Indeed, nitrogen oxides – primarily produced by vehicle emissions – have the potential to alter soil chemistry and thus alter the competitive balance between plant species (Cole, 2004; Littlemore, 2006). A study of woodland adjacent to the M6 motorway has shown that engine particulates may be deposited on trees as far as 200m away, and can cause a substantial reduction in the health of trees such as sessile oak *Quercus petraea* and beech *Fagus sylvatica* (Freer-Smith et al., 1997).

7.4 Increased greenhouse gas emissions:

- Most estimates of greenhouse gas emissions associated with shale gas generated energy have drawn upon a narrow set of primary data from shale gas operations in the US, and incorporate a number of significant uncertainties (such as the level of emissions associated with the well completion stage, site specific geological and other factors which determine the rate of gas return at the well head, levels of water re-use and the energy required for the treatment of waste water) (Broderick et al., 2011; Forster and Perks, 2012).
- This has led to disagreement about the extent to which shale gas can be considered a relatively "green" alternative to traditional fossil fuels (i.e. conventional natural gas, coal and oil), with some studies suggesting that, due in part to recent advances in our understanding of the potency of methane as a greenhouse gas (e.g. Shindell et al., 2009), the impact of shale gas on climate change may be even greater than other types of fossil fuels. Indeed, Howarth et al. (2011), argue that the greenhouse gas footprint for shale gas is even greater than conventional gas or oil when viewed on

any time horizon, but particularly so over 20 years, and that, when compared to coal, the footprint of shale gas is at least 20% greater and perhaps more than twice as great on the 20-year horizon, only becoming similar in magnitude when compared over 100 years.

- Nevertheless, the majority of studies suggest that greenhouse gas emissions from shale gas are likely to be lower than coal, but higher than conventional gas (Broderick et al., 2011; Forster and Perks, 2012; DECC, 2013a).
- Indeed, a recent report (produced for the European Commission Directorate-General for Climate Action and designed to investigate relative levels of greenhouse gas emissions in a European, rather than US, context) found that, whilst emissions from shale gas generation are likely to be significantly lower (41% to 49%) than emissions from electricity generated from coal, greenhouse gas emissions per unit of electricity generated from shale gas may be around 4% to 8% higher than for electricity generated by conventional pipeline gas sourced from within Europe (Forster and Perks, 2012). Although, interestingly, emissions from shale gas generated electricity are predicted to be 2% to 10% lower than emissions from electricity generated from sources of conventional pipeline gas located outside of Europe (e.g. in Russia and Algeria), and 7% to 10% lower than that of electricity generated from Liquefied Natural Gas imported into Europe (Forster and Perks, 2012).
- However, due to the aforementioned uncertainties involved in estimating greenhouse gas emissions, these predictions are subject to considerable uncertainty. Indeed, despite the fact that the majority of emissions occur during the relatively easy to predict combustion stage (rather than during the much more uncertain pre-combustion processes that form part of extraction and processing), the huge uncertainty regarding emissions generated during pre-combustion activity mean that overall emissions predictions could severely underestimate overall emissions levels from shale gas (Broderick et al., 2011; Forster and Perks, 2012).
- Most of the uncertainty regarding pre-combustion emissions comes from so-called “fugitive emissions” (i.e. methane gas escaping un-captured at the well head), which, traditionally in gas and oil extraction, are disposed of by either flaring (i.e. the controlled burning of natural gas during the course of oil and gas production operations) or venting (i.e. the controlled release of natural gas into the atmosphere, also commonly practiced during the course of gas and oil production operations) (The International Association of Oil and Gas Producers, 2000).
- In theory these fugitive emissions can be reduced through a practice known as “Reduced Emissions Completions” (also known as “green completions” or ”reduced flaring completions”), in which a proportion of the fugitive gases produced during flowback are captured and processed on-site for sale (EPA, 2011b; Forster and Perks, 2012). Indeed, evidence from the US EPA Gas Star programme suggests that Emissions Completions may reduce fugitive methane emissions from well completions by around 90%. However, emissions reductions of this magnitude depend on a range of factors which may or may not be exist in a UK context, such as: sufficient gas pressure (i.e. above 500 pounds per square inch), the availability of appropriate infrastructure for such on site processing, and the required experience and expertise to manage such an operation (EPA, 2011b; Forster and Perks, 2012). Moreover, these theoretical emission reductions figures do not take account of methane emitted during “drill-out” – the stage in the development of unconventional gas in which the plugs set to separate fracturing stages are drilled out to release gas for production – which could account for as much as 50% of all fugitive methane emissions (Howarth et al., 2011).
- Finally, there is a risk that greenhouse gas emissions will continue to increase even if shale gas is produced due to the fact that, as natural gas production increases as a result of fracking, coal previously used for domestic energy generation may simply be shipped elsewhere. This process of exporting emissions is already happening in the US, where the exploitation of shale gas is rapidly advancing; indeed, despite US domestic coal consumption falling by about 114 million tons (11%) in 2012 (largely due to a decline in the use of coal for electricity), coal production still increased 17%, with overseas shipments surpassing the previous high mark set in 1981 by 12% (Grose, 2013).

8. What are the potential impacts in the High Weald AONB?

Due to the fact that the UK shale gas industry is still in the exploration stage, with no commercial drilling operations currently producing shale gas, an assessment of the impacts that full-blown fracking activity would have on a particular landscape can only be speculative. However, the following examples of impacts of fracking have occurred elsewhere, and are examined in the High Weald context to indicate some of the possible risks~~.~~

- Pollution of the High Weald's ground and surface water. Groundwater contamination by fracking appears unlikely to occur during the drilling process itself (particularly if activity is regulated as thoroughly as the UK government states it will be (DECC, 2013a)). Similarly, given the tighter regulations regarding above ground wastewater storage in the UK than in the US, surface water pollution by fracking fluids also appears unlikely. It is possible that over longer timescales (i.e. 50+ years) some pollution and contamination may occur. This may arise as a result of well degradation and re-pressurisation (Bishop, 2011; Dusseault et al., 2000). Elevated sediment runoff into streams as a result of vegetation clearance and stream disturbance during well pad and infrastructure development is possible (Willams et al., 2008; Entrekin et al., 2011). Wastewater disposal – whether through injection underground, or via surface treatment/dilution – also poses a risk to the region's surface and groundwater resources.

- Increased stress on the region's water resources. Fracking operations require significant quantities of water in order to function. Depending on the scale of any future fracking activity in the High Weald AONB, hydraulic fracturing could contribute to increased stress on the region's water supply – particularly in view of the fact that the High Weald AONB is located in one of the driest parts of the UK (South East Water, 2013). (The following web page provides information on the role South East Water would play in supplying – and monitoring – water for any future fracking activity: http://www.southeastwater.co.uk/news-and-information/information/fracking-your-questions-answered#.UkMI_xbkgyI).

- Impacts on the High Weald's aesthetic and recreational resources.
  Fracking sites usually require an area at least 1ha in size, and involve excavation, levelling and earth movement. The ongoing operations also require the transportation of significant quantities of equipment and materials, including around 200 tanker truck deliveries of water for a single hydrofrack "event" (Entrekin et al., 2011; Frac Focus, 2013b; ProPublica, 2013)). Both the physical development of the site, and its ongoing operation, present potentially significant impacts on the quality and character of the landscape. Recreation in the High Weald, and consequently revenue and employment in the region's tourism industry, may be adversely affected.

- Road congestion and damage. A fracking site may require additional and extending lorry movements and increase local road usage. Such congestion would likely be particularly acute if road usage for a fracking operation involved the use of smaller roads and lanes. Historic routeways, with their important archaeological and ecological features, may also be damaged by increases in traffic, particularly heavy trucks and lorries.

- Local ecological damage. Ecological damage can potentially occur through Nitrogen oxide and engine particulates pollution (Corney et al., 2008). These have the potential to alter soil chemistry and thus plant composition (Cole, 2004; Littlemore, 2006), as well as damage the health of trees (Freer-Smith et al., 1997).

- Minor earthquake damage. Although current research suggests the risk of structurally damaging earthquakes being cause by hydraulic fracturing is very low, this risk can vary depending on a variety of factors. These factors include: the extent to which the geology underlying a drilling operation is faulted, the amount of pre-existing tectonic stress in any faults that are present, and the quantities of fluid being extracted and injected, as well as the proximity of this extraction and injection activity to any pre-existing geologic faults. Thus, the potential for structurally damaging fracking-induced earthquakes to occur depends to a large extent on local geological conditions, as well as the way in which fracturing and wastewater disposal operations are performed.

References

ANDREWS, I. J., 2013. *The Carboniferous Bowland Shale gas study: geology and resource estimation*. London: British Geological Survey for the Department of Energy and Climate Change. Available from: https://www.gov.uk/government/publications/bowland-shale-gas-study [Accessed 20th August 2013].

API, 2009. Hydraulic fracturing operations: well construction and integrity guidelines, API guidance document HF1. Washington DC: American Petroleum Institute. Available from: http://www.shalegas.energy.gov/resources/HF1.pdf [Accessed 20th August 2013].

BICKLE, M., GOODMAN, D., MAIR, R., ROBERTS, R., SELLEY, R. C., SHIPSTON, Z., THOMAS, H. and YOUNGER, P., 2012. Shale gas extraction in the UK: a review of hydraulic fracturing. The Royal Society & The Royal Academy of Engineering. Available from: royalsociety.org/uploadedFiles/Royal_Society_Content/policy/projects/shale-gas/2012-06-28-Shale-gas.pdf [Accessed 19th August 2013].

BISHOP, R. E., 2011. Chemical and Biological Risk Assessment for Natural Gas Extraction in New York. New York: Chemistry & Biochemistry Department State University of New York, College at Oneonta Sustainable Otsego. Available from: http://www.sustainableotsego.org/Risk%20Assessment%20Natural%20Gas%20Extraction-1.htm [Accessed 27th August 2013].

British Geological Survey, 2012. *The Unconventional Hydrocarbon Resource Of Britain's Onshore Basins – Shale Gas*. London: British Geological Survey for the Department of Energy and Climate Change. Available from: https://www.og.decc.gov.uk/UKpromote/onshore_paper/UK_onshore_shalegas.pdf [Accessed 20th August 2013].

British Geological Survey, 2013a. Earthquake Intensity. Available from: http://www.bgs.ac.uk/discoveringGeology/hazards/earthquakes/intensity.html [Accessed 30th August 2013].

British Geological Survey, 2013b. Baseline methane survey of UK groundwaters. Available from: http://www.bgs.ac.uk/research/groundwater/quality/methane_baseline_survey.html [Accessed 22nd August 2013].

BRODERICK, J., ANDERSON, K., WOOD, R., GILBERT, P., SHARMINA, M., FOOTITT, A., GLYNN, S. and NICHOLLS, F., 2011. Shale gas: an updated assessment of environmental and climate change impacts, The Co-operative and the University of Manchester. Available from: http://www.cooperative.coop/Corporate/Fracking/Shale%20gas%20update%20-%20full%20report.pdf [Accessed 22nd August 2013].

CATFORD, N., 2010. Disused Stations Site Record: Heathfield, Sussex. Available from: http://www.disused-stations.org.uk/h/heathfield_sussex/ [Accessed 19th August 2013].

COLE, D. N., 2004. Impacts of hiking and camping on soils and vegetation: a review. In: R. Buckley ed. Environmental impacts of ecotourism. Wallingford UK; CAB International, 2004. pp.41-60.

CORNEY, P. M., SMITHERS, R. J., KIRBY, J. S., PETERKEN, G. F., Le DUC, M. G. and MARRS, R. H., 2008. Impacts of nearby development on the ecology of ancient woodland. Report commissioned by the Woodland Trust. Available from: http://www.woodlandtrust.org.uk/SiteCollectionDocuments/pdf/policy-andcampaigns/woodwatch/impacts-development-on-ecology-ancient-woodland.pdf [Accessed 30th August 2013].

DECC, 2012a. New controls announced for shale gas exploration. Available from: http://webarchive.nationalarchives.gov.uk/20121217150421/http://www.decc.gov.uk/en/content/cms/news/pn12_164/pn12_164.aspx [Accessed 20th August 2013].

DECC, 2012b. Government response to Royal Academy of Engineering and Royal Society report on “Shale Gas Extraction in the UK: a review of hydraulic fracturing”. Available from: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/49541/7269-government-response-sg-report-.pdf [Accessed 30th August 2013].

DECC, 2013a. About shale gas and hydraulic fracturing (fracking). Available from: https://www.gov.uk/government/publications/about-shale-gas-and-hydraulic-fracturing-fracking [Accessed 20th August 2013].

DECC, 2013b. Oil and gas: licensing rounds. Available from: https://www.gov.uk/oil-and-gas-licensing-rounds#th-licence-round-1 [Accessed 20th August 2013].

DUSSEAULT, M. B., GRAY, M. N. and NAWROCKI, P., 2000. Why Oilwells Leak: Cement Behavior and Long-Term Consequences. *Society of Petroleum Engineers*, International Oil and Gas Conference and Exhibition, Beijing, China, November 7–10, 2000.

ELLSWORTH, W. L., 2013. Injection-Induced Earthquakes. *Science*, 301, pp.142-149.

Energy & Capital, 2013. The Depth of Oil Wells. Available from: http://www.energyandcapital.com/resources/the-depth-of-oil-wells [Accessed 29th August 2013].

Energy Global, 2013. Cuadrilla resumes drilling at Balcombe. Available from: http://www.energyglobal.com/news/drilling-and-production/articles/Cuadrilla_resumes_drilling_at_Balcombe.aspx#.Uh8ogH_-Wrs [Accessed 29th August 2013].

ENTREKIN, S., EVANS-WHITE, M., JOHNSON, B. and HAGENBUCH, E., 2011. Rapid expansion of natural gas development poses a threat to surface waters. *Frontiers in Ecology and Environment*, 9 (9), pp.503-511. Available from: http://www.scribd.com/doc/74622611/Shale-Gas-Threats-to-Surface-Water [Accessed 20th August 2013].

EPA, 2011a. Plan to study the potential impacts of hydraulic fracturing on drinking water resources. Washington DC: US Environmental Protection Agency. Available from: http://water.epa.gov/type/groundwater/uic/class2/hydraulicfracturing/upload/final-study-plan-hf_web_2.pdf [Accessed 20th August 2013].

EPA, 2011b. Natural Gas STAR Program, Reduced Emissions Completions for Hydraulically Fractured Natural Gas Wells. Available from: http://www.epa.gov/gasstar/documents/reduced_emissions_completions.pdf [Accessed 28th August 2013].

Environment Canterbury, 2011. Earthquake magnitude and intensity. Available from: http://ecan.govt.nz/advice/emergencies-and-hazard/earthquakes/pages/earthquake-magnitude-intensity.aspx [Accessed 30th August 2013].

Explore Shale, 2013. How much water is used to frack a well? Available from: http://exploreshale.org/ [Accessed 27th August 2013].

FORSTER, D. and PERKS, J., 2012. Climate impact of potential shale gas production in the EU: Final Report. Produced by Ricardo-AEA for European Commission DG CLIMA. Available from: http://ec.europa.eu/clima/policies/eccp/docs/120815_final_report_en.pdf [Accessed 22nd August 2013].

Frac Focus, 2013a. Hydraulic Fracturing Water Usage. Available from: http://fracfocus.org/water-protection/hydraulic-fracturing-usage [Accessed 22nd August 2013].

Frac Focus, 2013b. Site Setup. Available from: http://fracfocus.org/hydraulic-fracturing-how-it-works/site-setup [Accessed 22nd August 2013].

FREER-SMITH, P. H., HOLLOWAY, S. and GOODMAN, A., 1997. The uptake of particulates by an urban woodland: Site description and particulate composition. Environmental Pollution, 95, pp. 27-35.
FROHLICH, C. and BRUNT, M., 2013. Two-year survey of earthquakes and injection/production wells in the Eagle Ford Shale, Texas, prior to the Mw4.8 20 October 2011 earthquake. *Earth and Planetary Science Letters*, 379, pp.56-63.

GREEN, C. A., STYLES, P. and BAPTIE, B. J., 2012. Preese Hall Shale Gas Fracturing Review & Recommendations for Induced Seismic Mitigation. Department of Energy and Climate Change: London. Available from: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/15745/5075-preese-hall-shale-gas-fracturing-review.pdf [Accessed 22nd August 2013].

GROSE, T. K., 2013. As U.S. Cleans Its Energy Mix, It Ships Coal Problems Abroad. Available from: http://news.nationalgeographic.co.uk/news/energy/2013/03/130315-us-coal-exports/ [Accessed 28th August 2013].

Heathfield Town, 2013. Historical Information – The Discovery of Natural Gas in Heathfield. Available from: http://www.heathfield.net/historical-information [Accessed 20th August 2013].

HOLZMAN, D. C., 2011. Methane Found in Well Water Near Fracking Sites. *Environmental Health Perspectives*, 119 (7), pp.289.

Institute of International and European Affairs, 2013. Step on the Gas? Shale Gas in Europe. Available from: http://www.iiea.com/blogosphere/step-on-the-gas-shale-gas-in-europe?gclid=CNX5iLSKkbkCFYdc3godrCgAhQ [Accessed 28th August 2013].

JACKSON, R. B., PEARSON, R. B., OSBORN, S. G., WARNER, N. R. and VENGOSH, A., 2011. Research and policy recommendations for hydraulic fracturing and shale-gas extraction. Center on Global Change: Duke University, Durham, NC.

KARGBO, D. M., WILHELM, R. G., and CAMPBELL, D. J., 2010. Natural gas plays in the Marcellus shale: challenges and potential opportunities. *Environmental Science* and *Technology Library*, 44, pp.5679–5684.

KCC, 2010a. Main Details for application: Woodnesborough, Kent. Available from: http://host1.atriumsoft.com/ePlanningOPSkent/loadFullDetails.do;jsessionid=0a80a71130d806fdb0b17edf43e487f5ea86e801efa5.e3mObhiLaxv0aheOaNeOaheKby0?aplId=34407 [Accessed 29th August 2013].

KCC, 2010b. Main Details for application: Cowden Exploration Site. Available from: http://host1.atriumsoft.com/ePlanningOPSkent/loadFullDetails.do?aplId=37527 [Accessed 29th August 2013].

LITTLEMORE, J., 2006. Quantifying the Visitor Carrying Capacity of Wildlife Habitats in the British Countryside – an Ecological Indicator of Sustainability. Journal of Practical Ecology and Conservation, 6 (1), pp.29-36.

MANUAL, J., 2010. EPA Tackles Fracking. *Environmental Health Perspectives*, 118 (5), pp.199.
MOONEY, C., 2011. The Truth About Fracking. *Scientific American*, November 2011, pp.80-85.

MOORE, S., 2012. Gas works? Shale gas and its policy implications. London: Policy Exchange. Available from:
http://www.policyexchange.org.uk/images/publications/gas%20works%20-%20feb%2012.pdf [Accessed 30th August 2013].

MOYLAN, J., 2013. UK shale gas reserves may be 'bigger than first thought'. Available from: http://www.bbc.co.uk/news/business-22748915 [Accessed 20th August 2013].

OSBORN, S. G., VENGOSH, A., WARNER, N. R. and JACKSON, R. B., 2011. Methane contamination of drinking water accompanying gas-well drilling and hydraulic fracturing. *Proceedings of the National Academy of Sciences*, 108 (20), pp.8172-8176. Available from: http://www.pnas.org/content/early/2011/05/02/1100682108.full.pdf+html [Accessed 27th August 2013].

Penn Staten, 2011. Multi-Well Pads in the Marcellus Shale. Available from: http://extension.psu.edu/natural-resources/natural-gas/news/2011/10/multi-well-pads-in-the-marcellus-shale [Accessed 22nd August 2013].

ProPublica, 2013. What Is Hydraulic Fracturing? Available from: http://www.propublica.org/special/hydraulic-fracturing-national [Accessed 29th August 2013].

Regeneris Consulting, 2011. Economic Impact of Shale Gas Exploration & Production in Lancashire and the UK. A Report prepared for Cuadrilla Resources, Regerneris Consulting Limited, September 2011. Available from: http://www.cuadrillaresources.nl/wp-content/uploads/2012/02/Full_Report_Economic_Impact_of_Shale_Gas_14_Sept.pdf [Accessed 28th August 2013].

SELLEY, R. C., 2012. UK shale gas: The story so far. *Marine and Petroleum Geology*, 31, pp.100-109. Available from: http://www.sciencedirect.com/science/article/pii/S0264817211002030 [Accessed 20th August 2013].

SHINDELL, D. T., FALUVEGI, G., KOCH, D. M, SCHMIDT, G. A., UNGER, N. and BAUER, S. E., 2009. Improved attribution of climate forcing to emissions. *Science*, 326, pp.716–718.

SCHOENMAKERS, J., 2009. Guidelines for the suspension and abandonment of wells. London: Oil & Gas UK.

SMITH, N., TURNER, P. and WILLIAMS, G., 2010. UK data and analysis for shale gas prospectivity. *In*: B. A. VINING and S. C. PICKERING, eds. *Petroleum Geology : From Mature Basins to New Frontiers : Proceedings of the 7th Petroleum Geology Conference.* London: Geological Society of London, 2010, pp.1087-1098.

South East Water, 2013. Managing existing resources. Available from: http://www.southeastwater.co.uk/our-environment/water-resources/planning-for-the-future/managing-existing-resources#.UlvrT1OLCzg [Accessed 14th October 2013].

STOTT, E., 2013. MP 'clueless over fracking'. Available from: http://www.kentonline.co.uk/thanet_extra/news/mp-clueless-over-fracking-4980/ [Accessed 29th August 2013].

The International Association of Oil and Gas Producers, 2000. Flaring & venting in the oil & gas exploration & production industry: An overview of purpose, quantities, issues, practices and trends. Report No. 2.79/288, January 2000. Available from: http://www.ogp.org.uk/pubs/288.pdf [Accessed 29th August 2013].

United States Energy Information Administration, 2011. World Shale Gas Resources: an initial assessment of 14 regions outside the United States. Report prepared by Advanced Resources International Inc. Available from: www.eia.gov/analysis/studies/worldshalegas/ [Accessed 19th August 2013].

US Geological Survey, 2013. Magnitude/Intensity Comparison. Available from: http://earthquake.usgs.gov/learn/topics/mag_vs_int.php [Accessed 30th August 2013].

WILLIAMS, H. F. L., HAVENS, D. L., BANKS, K. E. and WACHAL, D. J., 2008. Field-based monitoring of sediment runoff from natural gas well sites in Denton County, Texas, USA. *Environmental Geology*, 55, pp.1463–71.

WSCC, 2010. Main details for application: Lower Stumble Hydrocarbon Exploration Site. Available from: http://buildings.westsussex.gov.uk/ePlanningOPS/loadFullDetails.do?aplId=1154 [Accessed 29th August 2013].