Hydraulic Fracturing or ‘Fracking’: A Short Summary of Current Knowledge and Potential Environmental Impacts

A Small Scale Study for the Environmental Protection Agency (Ireland) under the Science, Technology, Research & Innovation for the Environment (STRIVE) Programme 2007 – 2013

Prepared by: Dr Dave Healy
Senior Lecturer in Geomechanics
Department of Geology & Petroleum Geology
University of Aberdeen
Aberdeen
AB24 3UE
United Kingdom
d.healy@abdn.ac.uk

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Peer Review

This report was peer-reviewed before release by internal (EPA) reviewers and by an academic expert based in Ireland. The EPA managed the peer review process.

Preface

The extraction of shale gas on a commercial scale is an activity that is licensable by the Environmental Protection Agency (EPA) of Ireland. While such activity is not likely to occur in the near future, it is likely that permits for exploration in the Lough Allen basin may be sought from the Department of Communications, Energy & Natural Resources (DoCENR) in the next 2 years, which may seek to perform extraction on a small scale as part of the exploration. Such permit applications may seek approval to use hydraulic fracturing techniques, known as 'fracking'. This method of gas extraction has never previously been used on a commercial basis in Ireland. It is envisaged that the EPA will be a statutory consultee with respect to any Environmental Impact Assessment required for shale gas projects at the exploration stage, and will therefore be required to gain expert knowledge on the environmental impacts in order to fulfil this role. Such knowledge would also be required to assess any licence applications for commercial gas extraction in the future. This preliminary report aims to constrain this knowledge base by documenting what is currently known and understood about fracking and the potential environmental impacts, and will help to form the basis for a larger and more detailed research study.

The objectives of this preliminary report are to provide information:

- on the potential environmental impacts of fracking in particular, and shale gas extraction in general, e.g. methane and chemical migration into ground water;
- on the role of geology in successful fracking and shale gas extraction;
- on the regulatory approaches of other countries;
- on the establishment of Best Environmental Practice; the possibility of fracking without the use of chemicals is investigated in this context.

This report contains the following elements:

- Introduction & Context
- Geological Principles of Relevance in Fracking & Shale Gas Extraction
- Potential Environmental Impacts
- Regulatory Approaches in Other Countries
- Establishing Best Environmental Practice

In conducting research for this report, independent sources have been used, and verified where possible.

Introduction & Context

Hydraulic fracturing, or 'fracking', is a method used by drilling engineers to stimulate or improve fluid flow from rocks in the subsurface. In brief, the technique involves pumping a water-rich fluid into a borehole until the fluid pressure at depth causes the rock to fracture. The pumped fluid contains small particles known as proppant (often quartz-rich sand) which serve to prop open the fractures. After the fracking job, the pressure in the well is dropped and the water containing released natural gas flows back to the well head at the surface. The boreholes themselves are often deviated away from the vertical, into subhorizontal orientations, to ensure better and more efficient coverage of the targeted shale gas reservoir. The fracking fluid also contains small amounts (typically < 2% in total by volume) of chemical additives such as acid to help initiate fractures, corrosion and scale inhibitors to protect the borehole lining and gelling agents to alter the fluid viscosity.

A variety of factors have combined to promote the recent surge in the exploitation of shale gas. Most traditional hydrocarbon reservoirs developed to date have oil and gas located in well connected pores in the rock. This natural porosity, and related permeability, is often sufficient to allow extraction, but various methods of stimulation have been used over many years to improve the flow rate, including fracking. In shale gas reservoirs, the natural gas is more closely bound to the rock, and sits in a fine scale array of relatively isolated and small pores and cracks. In order to extract this resource, the permeability must be improved by artificial means, and fracking is a popular method. Injecting large volumes of fluid into the subsurface is not without risk, and recent reports in the media and, to a much lesser extent, in the scientific literature have highlighted the potential for the following:

- earthquakes induced by slip on nearby faults;
- contamination of ground water, and possibly even drinking water, with natural gas and other chemicals;
- emissions of volatile components, such as CO_2 or methane, into the atmosphere;
- the leakage of contaminated drilling waste fluid from storage ponds.

This document reviews the geological and engineering aspects of fracking, the potential environmental impacts, and the existing regulatory framework in different countries. It concludes with recommendations for further study and information to help guide Best Practice.

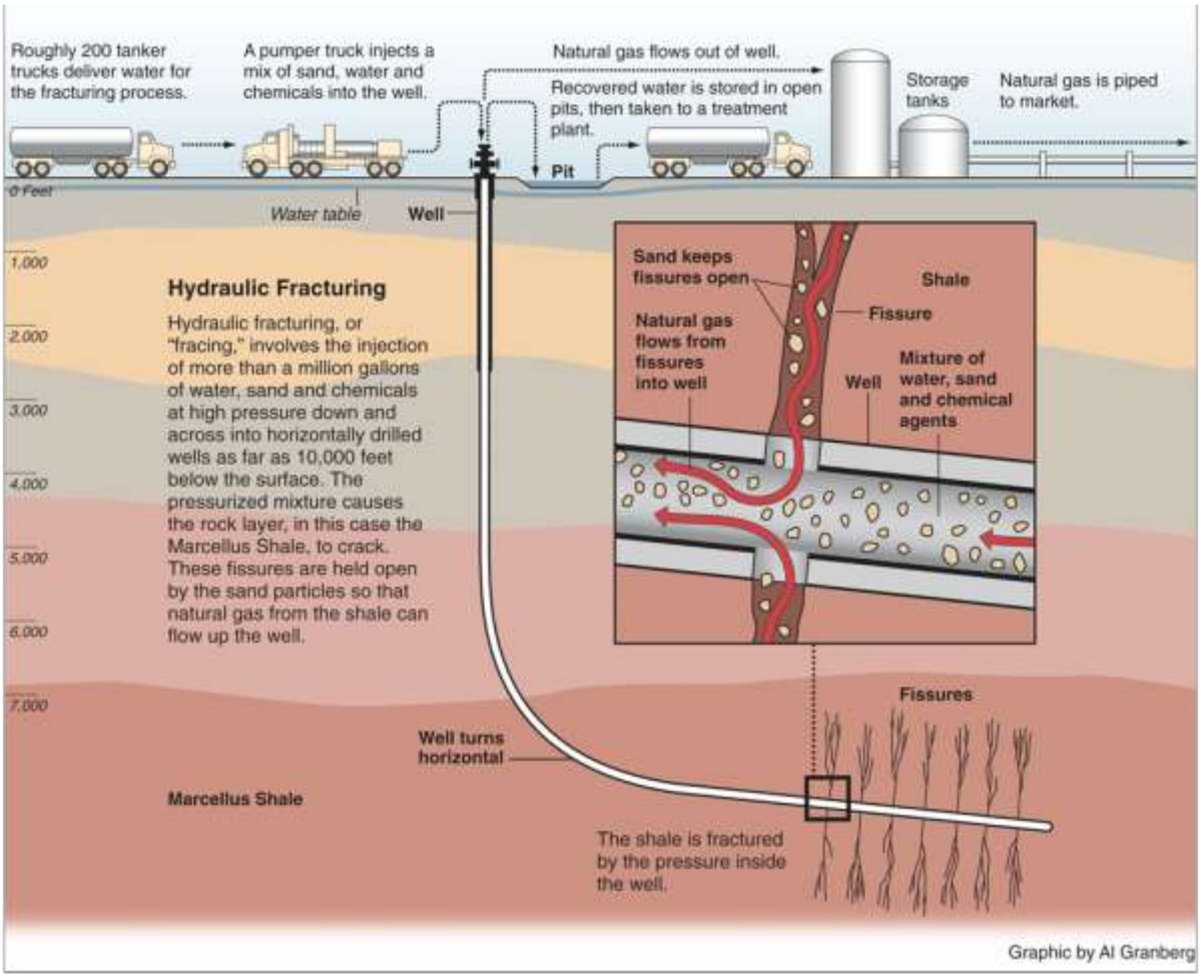


Figure 1. Schematic diagram showing the general features of a fracking operation. Source: ProPublica web site http://www.propublica.org/series/fracking.

Geological Principles of Fracking & Shale Gas Extraction

Some of the key geological issues with relevance to the potential environmental impacts of fracking are:

- the relatively limited understanding of rock fracture patterns and processes in shales;
- the ability to predict and quantify permeable fracture networks in the subsurface before drilling;
- the accuracy and precision with which the geometry (size or extent, position, thickness) of shale formations and aquifers in the subsurface can be determined, especially in areas with complex geological histories.

The ability of fluids to flow through rock is controlled by a property called permeability, itself a function of porosity. The pore space in rocks is made up of a diverse range of voids in the solid rock matrix and includes cracks induced by stresses. The aim of fracking is to massively improve permeability by creating (or reopening) a locally dense network of open and connected – i.e. hydraulically conductive – fractures.

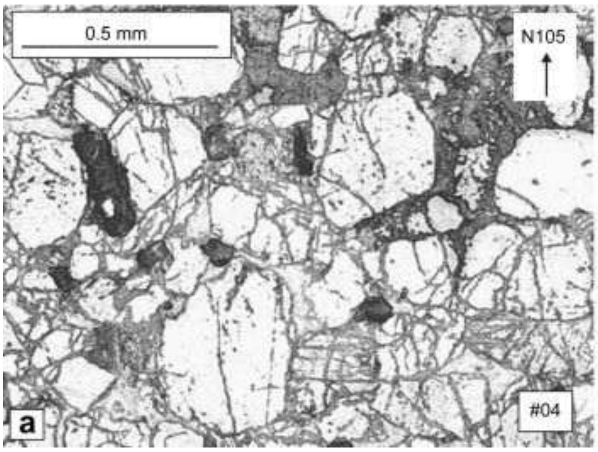


Figure 2. Photomicrograph of a fractured rock showing the intricate network of grains, pores and cracks. Permeability can be improved by inducing new fractures and connecting more of them together.

Source: Louis et al., 2008.

Rock fracture

The nucleation and propagation of hydraulic rock fractures are chiefly controlled by the local *in situ* stress field, the strength of the rock (stress level needed to induce failure), and the pore fluid pressure (Secor, 1965; Phillips, 1972). Temperature, elastic properties, pore water chemistry and the loading rate also have an influence. Fractures in rock can be classified as tensile, shear or hybrid (a mixture of tensile and shear). If the dominant displacement of the wall rocks on either side of the fracture is perpendicular to the fracture surface, then the fracture is deemed tensile. New tensile fractures form when the pore fluid pressure in the rock exceeds the sum of the stress acting in a direction perpendicular to the fracture wall and the tensile strength of the rock. Note that any pre-existing fractures that are uncemented (i.e. have zero cohesion) can be opened at a lower value of pore fluid pressure, when it exceeds the stress acting in a direction perpendicular to the fracture wall. The formation or reactivation of shear fractures depends on the shear stress, the normal stress, the pore fluid pressure and the coefficient of friction for the specific rock type.

It is important to recognise that the fracking process of pumping large volumes of water into a borehole at a certain depth cannot control the type of fractures that are created or reactivated. The array of fractures created and/or reactivated or reopened depends on a complex interplay of the *in situ* stress, the physical properties of the local rock volume and any pre-existing fractures, and the pore fluid pressure (Phillips, 1972). This could have implications for the risk of ground water contamination by fracking operations, as the fracture network generated by the fracking fluid could be complex and difficult to predict in detail. The orientations, sizes and apertures of permeable rock fractures created by a fracking operation ultimately control the fate of the fracking fluid and the released shale gas, at least in the deep subsurface. Geomechanical models used to predict these fracture pattern attributes therefore need thorough testing/benchmarking, together with ongoing and future developments.

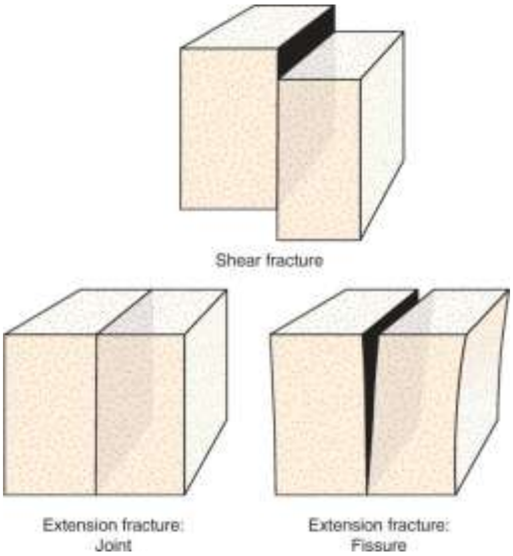


Figure 3. Diagram showing the main fracture types, extension fractures (joints and fissures) and shear fractures.

Source: Fossen, 2010.

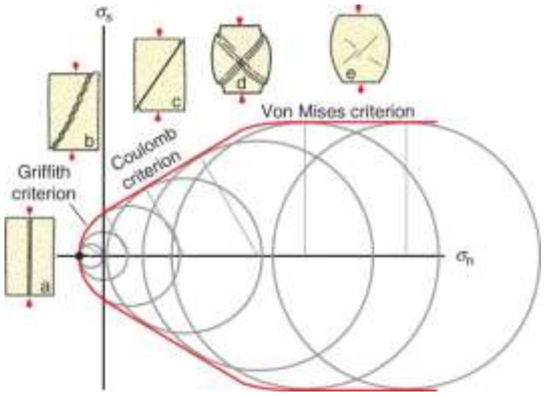


Figure 4. Diagram showing the relationship between fracture type and stress on a Mohr plot. Tensile (or extension) fractures are labelled a) and b), shear fracture is labelled c). When the stress state in the rock meets the failure envelope (red line, rock specific), the rock will fracture.

Source: Fossen, 2010.

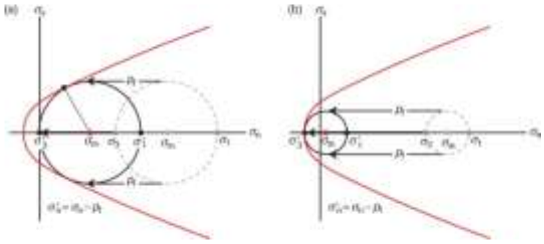


Figure 5. Diagram showing the effect of an increase in pore fluid pressure. The original stress state (dashed circle) is modified and driven towards the failure envelope (red line). For high differential stress (bigger stress circle, left), the rock will fail in shear, whereas for low differential stress (small circle, right) the failure mode will be tensile.

Source: Fossen, 2010.

Mechanical anisotropy

A recognised complicating factor in many shale gas formations is that of elastic anisotropy. Many rocks, including common hydrocarbon reservoir sandstones can be considered as elastically isotropic – i.e. their elastic properties, such as Young’s modulus and Poisson’s ratio, do not vary with direction. This is largely a consequence of the depositional process for granular rocks such as sandstones involving settling, sorting and compaction of more or less equant grains of quartz, each with a random orientation. In contrast, many shales are distinctly anisotropic in their elastic properties, as their constituent clay minerals are platy in form and are then compacted into aligned parallel layers. This gives a measurable and important directionality to their elastic and mechanical response.

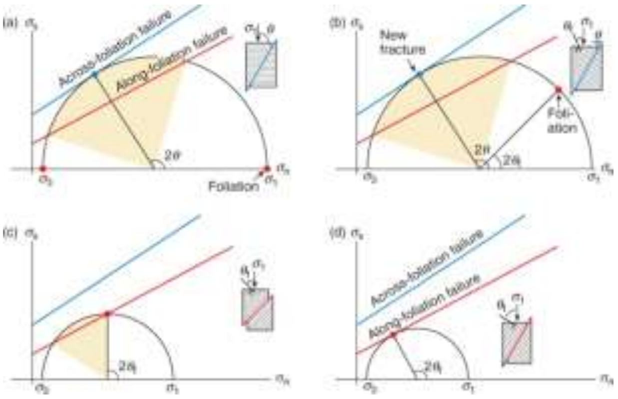


Figure 6. Diagram showing the effect of anisotropy on rock failure. Foliation is a term used to describe planar alignments of minerals in rock – many shales have a foliation of sorts. The failure envelopes for across and along the foliation are very different, and thus the rock will fracture at different stress levels. The critical issue is to know the angle between the stresses and the foliation.

Source: Fossen, 2010.

The precise physical nature of the control exerted by lithology anisotropy on rock fracture is poorly understood; although the effects are well known/documented. Many anisotropic rocks such as shale fail much more easily/frequently along/parallel to their fabric than across it and the orientation of any cross-cutting fractures is different to those orientations predicted for an isotropic rock in the same stress field. These observations have potentially important implications for the connectivity, and therefore permeability, of any fracking induced fracture array in anisotropic shales. As noted above, the exact details of the created fracture network are critical to the effective extraction of shale gas, but also for the ultimate fate of the injected fracking fluid (e.g. Geosphere, 2011). A better mechanical understanding of rock fracture in anisotropic rocks will help improve the predictive capabilities of geomechanical models, which also need to be tested under controlled conditions.

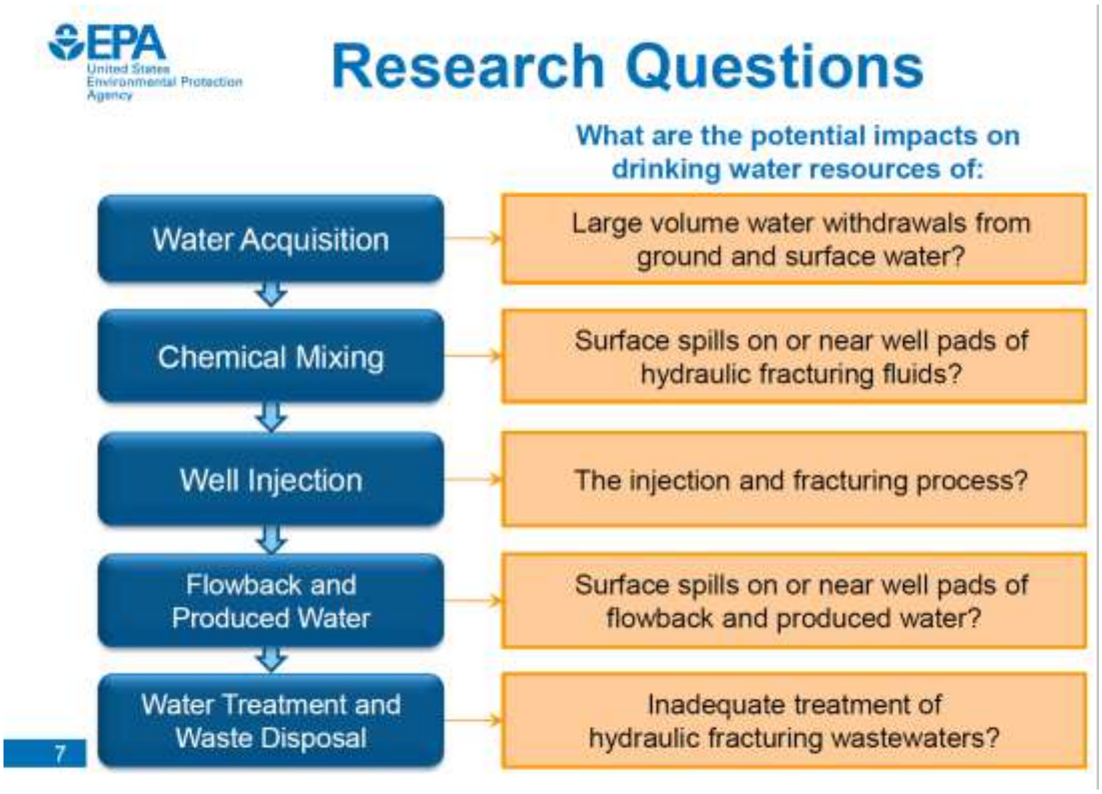
Geological risks

Fracking inherently involves geomechanical risks – i.e. the injection of large volumes of pressurised water at depth will, by design, alter the *in situ* stress state and change the propensity of existing fractures to open or faults to slip, and possibly result in seismic activity (i.e. earthquakes). If the *in situ* rock stresses and the pre-existing fracture network are known in advance of the drilling and fluid injection, the geomechanical risks of planned changes in pore fluid pressure can be quantified using methods based on slip and dilatation tendency (Morris et al. 1996; Ferrill et al., 1999). This approach is sometimes employed within the hydrocarbon industry though its predictive capability depends on data coverage and data quality. The stress model and the fault model used as inputs to the predictions need to be as accurate as possible, and any uncertainties need to be quantified. Two recent earthquakes near Blackpool in the UK have been attributed to fracking treatments applied at the nearby Preese Hall 1 well of Cuadrilla Resources (Cuadrilla). Detailed and comprehensive analyses by third parties after the earthquakes has shown that the most likely cause of the seismic activity was slip in a previously unmapped, highly permeable fault zone located near the base of the well (de Pater and Baisch, 2011; Geosphere, 2011). Diversion of much of the pumped water into this fault zone eventually led to the relief of sufficient stress to allow the fault to move, on at least two separate occasions, both events occurring shortly after large volume water injections at the well head. It has been pointed out that these fracking induced earthquakes were smaller than many historical events in the same region, attributed to coal mine collapse or natural tectonic processes, and much smaller than naturally induced earthquakes generally reported in the media. No subsurface geological model can ever be truly complete or perfect, but this example serves to highlight the need for careful and detailed definition of all the components (*in situ* stresses, fault and fracture network, rock properties) used as input to predictive models of geomechanical risk.

Fracking also entails geochemical or hydrogeological risks. The key issue is the fate of the water (plus additives) after the fracking has occurred. As discussed above, during fracking there is little direct control on the nature of the permeable fracture network created, and how this new network might then connect to any pre-existing (and potentially undetected) fracture network. Whilst potential contamination of ground water with the injected fracking fluid is therefore an important concern, another issue is the fate of the initial drilling fluid (or 'mud') used to lubricate the borehole during drilling. The industry as a whole is, however, well versed in conserving drilling mud, and boreholes are lined with metal casing tubes which are then cemented into place. An additional risk is that of the natural gas released by the fracking process entering the ground water, however there has only been one confirmed case of this kind of contamination to date, with natural gas released from a fracking operation entering a shallow aquifer through poor quality casing (Osborn et al., 2011; see below).

Potential Environmental Impacts

The coverage of the potential environmental impacts of fracking is currently dominated by material originating from the USA. Fracking has a long history in the United States, and statistically the number of proven environmental impacts demonstrated to have been caused by fracking remains small in relation to the volume of fracking activity. One estimate is that approximately one million oil and gas wells have been drilled and fracked (University of Texas, 2012). Public debate in the US and elsewhere is polarised between an industry-funded lobby on the one hand, and environmental groups on the other. Finding the 'truth' about the tangible impacts on the environment from the mass of published, non-peer reviewed material, much of it comprising claim and counter-claim, is non-trivial. There have been relatively few published, peer-reviewed scientific reports into the potential environmental impacts of fracking, but these studies show that the risks primarily depend on the quality and integrity of the borehole casing and cement job, rather than the fracking process itself. There are potentially significant risks from the nature and fate of the fluids used in the drilling and fracturing processes as well as the effects of the natural gas released. Possible further environmental impacts depend on the logistics of the extraction plan and the management of drilling operations at the surface which could involve relocating drilling rigs several times across a large area and over a protracted period.



EPA
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Research Questions

What are the potential impacts on drinking water resources of:

Water Acquisition → Large volume water withdrawals from ground and surface water?

Chemical Mixing → Surface spills on or near well pads of hydraulic fracturing fluids?

Well Injection → The injection and fracturing process?

Flowback and Produced Water → Surface spills on or near well pads of flowback and produced water?

Water Treatment and Waste Disposal → Inadequate treatment of hydraulic fracturing wastewaters?

Figure 6. Slide showing the scope of the US EPA investigation into the effects of fracking on drinking water, to be completed in 2012. Source: Environmental Protection Agency (USA).

Ground water contamination

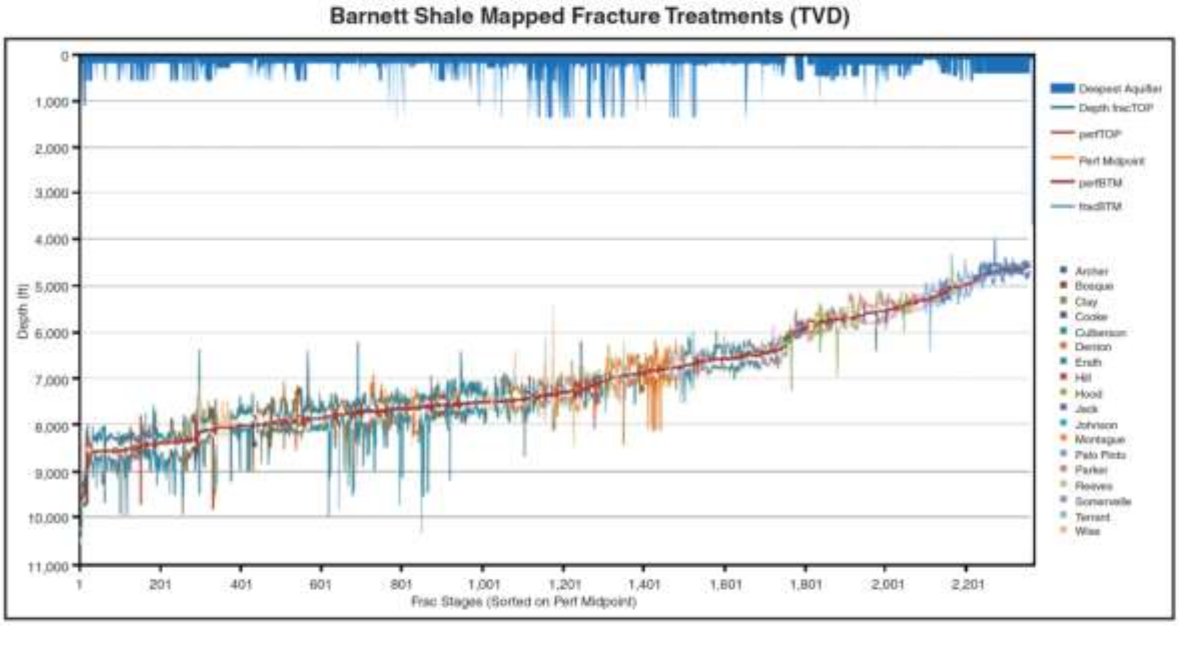
By far the most serious local environmental concern, and probably the most contentious, is that of ground water contamination. The potential risk to ground water comes from two sources: the injected fluid (water + chemical additives) and the released natural gas. There are alleged cases of both types (University of Texas, 2012; Osborn et al., 2011).

However, a key issue is the exact site of this contamination:

- percolation (advection) or diffusion from the hydraulically fractured formation at depth? or,
- leakage from a defective well bore closer to the land surface?

The current opinion shared by several agencies is that all scientifically documented cases of ground water contamination associated with fracking are related to poor well casings and their cements, or from leakages of fluid at the surface (Department of Energy & Climate Change (UK), 2012; University of Texas, 2012; Department of Energy (US), 2011; House of Commons Energy & Climate Change Committee (UK), 2011) rather than from the fracking process itself. The absence of evidence implicating leakage from a fracked fracture network could arise from the relatively short time span available for monitoring the signs of contamination, and potentially lower flow rates from a formation fracked at significant depth (several kilometres), although fracking has been performed in some areas for decades.

There may be an element of confusion in the media and in the wider public understanding, between contamination incidents from coal bed methane (or coal seam gas) fracking jobs, which occur at a relatively shallow depth closer to the water table, and alleged incidents from shale gas fracking, which is generally much deeper (thousands of feet or metres below the surface) and much further from any ground water aquifer and therefore presenting less of a risk for ground water contamination. That said, each shale gas play is unique and the detailed geometry of the shale formation in relation to local aquifers needs to be defined, and the risks of hydraulic connectivity between the two need to be fully evaluated before fracking operations begin. This issue of geometry, and the precision with which the geometry of subsurface rock formations can be quantified, is particularly important in regions where the tectonic structure (and history) are more complex e.g. NW Europe. Many US shale gas formations are relatively simple and flat lying, with aquifers positioned several kilometres above: this is not the case in many other basins around the world.



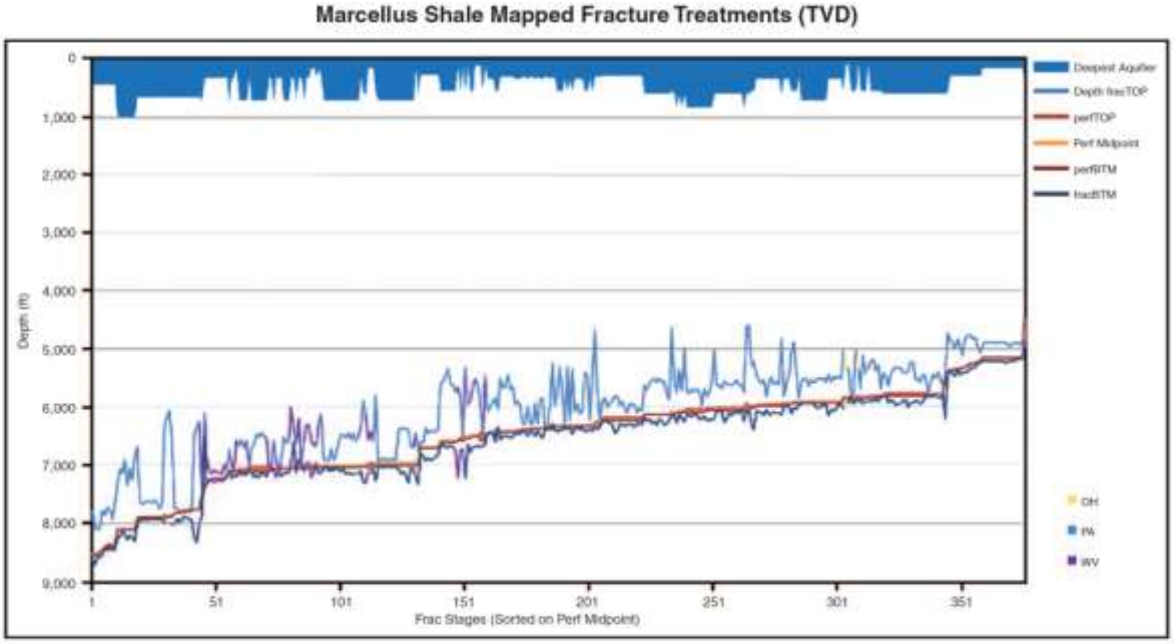


Figure 7. Graphs comparing the depth of deepest aquifers (from well data) and the mapped vertical extent of hydraulic fractures (from microseismicity and tilt meter data) in the Barnett and Marcellus Shale formations in the USA. Note that the mapped vertical extent of the fractures falls short of the deepest aquifers in all cases. Source: Fisher, 2010.

Results from a University of Texas study of several incidents of possible contamination in the US show no confirmed evidence for ground water contamination from the subsurface fracking operation itself, but suggest leakage stemming from fracking-related waste water above ground (University of Texas, 2012).

The potential risks identified from alleged incidents of ground water contamination so far include:

- overweight (or 'overbalanced') drilling mud causing leakage of drilling fluids from the well bore into near surface aquifers;
- contamination from solid components in the shale entering the flow back fluid;
- poor cement jobs on well bore casing, especially at shallow depths.

Overweight drilling mud can cause a well bore to fail by fracture. The density (or 'weight') of the drilling mud controls the fluid pressure exerted along the walls of the well bore. If the pressure of the mud exceeds the fracture pressure (strictly, the local minimum principal stress plus the fracture strength of the rock), then a fracture can form and the drilling fluid can escape. However, pressures exceeding the rock fracture strength generated by overweight drilling muds are only likely at great depths (several kilometres), far beyond the extent of any ground water aquifer, and so the risk of contamination from this issue is limited.

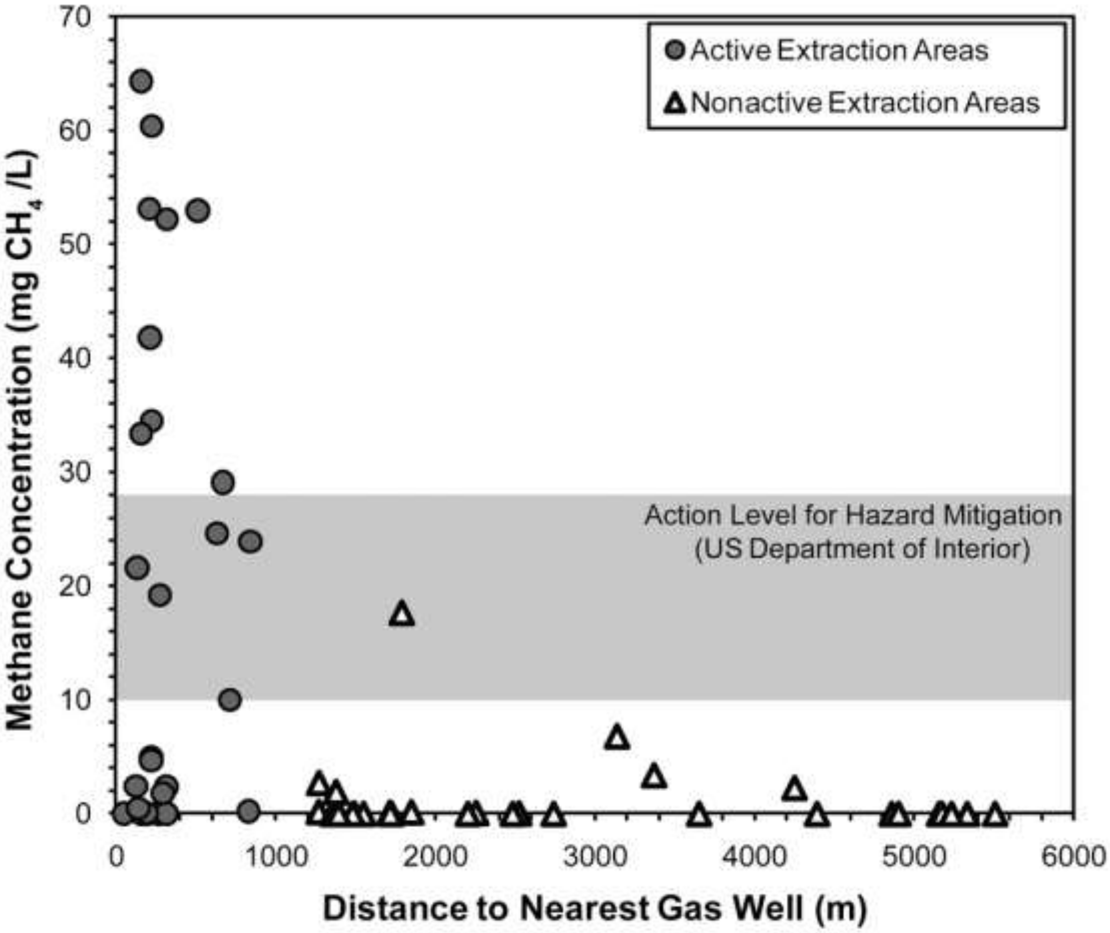


Figure 8. Graph showing the variation in measured methane (natural gas) concentration in ground water samples with distance from active and non-active wells in Pennsylvania, USA. Apparently, the concentrations are higher close to active wells. Note however, that there are no data points for non-active wells within similar distances as the active ones. Source: Osborn et al., 2011.

Many shales contain quantities of potentially harmful chemical elements and compounds that could be dissolved into the fracking fluid, and then return towards the surface during flow back. These include methane (i.e. the target natural gas to be released), carbon dioxide, hydrogen sulphide, nitrogen and helium; trace elements such as mercury, arsenic and lead; naturally occurring radioactive material (radium, thorium, uranium); and “volatile organic compounds” (VOCs) that easily vaporise into the air, such as benzene (House of Commons Energy & Climate Change Committee, 2011). The amount of material dissolved also varies widely, with estimates of between 13,000 and 120,000 ppm for shale gas plays in the USA (University of Texas, 2012). Careful chemical monitoring of fracking fluids, including the flow back fluid and produced water, is required to mitigate the risks of contamination from this source.

The boreholes drilled by industry are lined with lengths of casing pipe, which are then cemented into place, especially within the shallower depth interval (see Figure 10). The well bore may be left uncased at depth. The quality of the casing and the cement used to fix the casing in place is critical in safeguarding shallow level aquifers from contamination by drilling and fracking fluids (MIT, 2011). Strict regulation is required to mitigate against the use of poor quality casings.

Chemical additives

Defining the toxicity level of additives used in the fracking phase should be a relatively simple and quantifiable scientific task, however in some countries fracking companies are under no legal obligation to declare the exact composition of this mixture (see below). In fact, for companies operating in deregulated market economies there is a clear vested interest in keeping the fluid formula secret for competitive advantage. In order to test for and track potential chemical contamination, agencies responsible for monitoring and regulating the environmental impacts of fracking need to know the chemical composition of substances added to the fracking fluid. Note that the Irish regulatory regime (and that of the European Union) requires full disclosure of all additives to the Environmental Protection Agency (Ireland).

Blow outs

Surface and subsurface blow outs have been documented in the states of Texas, Louisiana, Ohio, Pennsylvania and Colorado in the US (University of Texas, 2012; The Huffington Post, 2011; ProPublica, 2008). If the fluid injected into the well head does not fracture the rock volume around the bottom of the well as intended, then the elevated fluid pressure will drive the fluid into other open and permeable pathways. These pathways can include the injecting well bore, but also any other boreholes in the vicinity that are not capped for these high pressures (e.g. other oil and gas wells or artesian wells used for drinking water). Explosive eruptions of drilling fluid and/or oil and gas from neighbouring wells are a direct consequence of pre-existing permeable connectivity at depth. Seepage of any surface spillage from a blow out into the ground could then lead to ground water contamination (see below).

Water sources

Sourcing the vast volumes of water required for an extended fracking programme can be challenging, especially in arid or depleted areas. Estimates of water volume required vary widely, with between 90,000 and 13,500,000 litres per well (MIT, 2011). Note that this large range is in part due to the large variation of well ‘lifetime’, with operations lasting from a matter of days through to many years (MIT, 2011). Local extraction of water from small catchments could have an impact on the ecology and hydrology of rivers in these areas. Finding sustainable sources for these volumes of water is clearly a challenge, but related environmental impacts may also develop from transporting water in to the drilling site from further afield: construction of new roads to remote drilling sites and increased heavy road traffic and pollution.

Play	Public Supply	Industrial/ Mining	Irrigation	Livestock	Shale Gas	Total Water Use (Bbbls/yr)
Barnett TX	82.7%	3.7%	6.3%	2.3%	0.4%	11.1
Fayetteville AR	2.3%	33.3%	62.9%	0.3%	0.1%	31.9
Haynesville LA/TX	45.9%	13.5%	8.5%	4.0%	0.8%	2.1
Marcellus NY/PA/WV	12.0%	71.7%	0.1%	<0.1%	<0.1%	85.0

Table 1. Table showing water usage of the major shale gas fracking operations in the USA, as a percentage of the total local water demand.

Source: MIT, 2011.

Fate of the fracking fluid

How to dispose of fracking fluid after use during the fracking process presents further challenges. Some operators in North America have chosen to pond this flow back fluid in man-made pools and then allow it to either evaporate, or be transported away at a later date. Evaporation leads to concentration of the chemical additives, increasing the potential for environmental impact if a leak develops. Breaching of these evaporation or temporary ponds (or the related pipe work) due to poor maintenance or poor design has in one instance led to contamination of local habitat and ground water supplies (New York Times, 2011). In Europe, flow back fluid may be formally classified as waste under the European Union Mining Waste Directive, and will then be subject to strict conditions during processing at the surface. At least one operator in the US has successfully reused the flow back fluid in the subsequent fracking operations at the same well head, with no loss in efficiency. However, the costs involved in processing the flow back fluid to remove any contaminants collected during the first cycle may deter wider application (Exploration & Production Magazine, 2010). Scope exists to develop new fracking fluids free from chemical additives, although the sand proppant will probably still be required. If such 'clean' fracking fluids can be shown to be as effective as those with chemical additives, then many of the alleged contamination risks associated with fracking could be reduced or eliminated.

Emissions to the atmosphere from fracking

An issue related to the fracking fluid is the emission of gas and/or vapour to the atmosphere from the fluid, either of original additive chemicals, entrained contaminants from the shale formation or the methane released by the fracking process. There is an ongoing debate about the relative leakage rate of methane into the atmosphere from the exploitation of shale gas in comparison to the emission rate from conventional gas (Howarth et al., 2011; Cathles et al., 2011). This is potentially important because a high leakage rate might mean that methane released by fracking operations into the atmosphere from shale gas extraction could have a higher net greenhouse gas footprint than, say, coal. Fracking operators should therefore seek to minimize all emissions to the atmosphere, and monitoring processes need to be actively enforced.

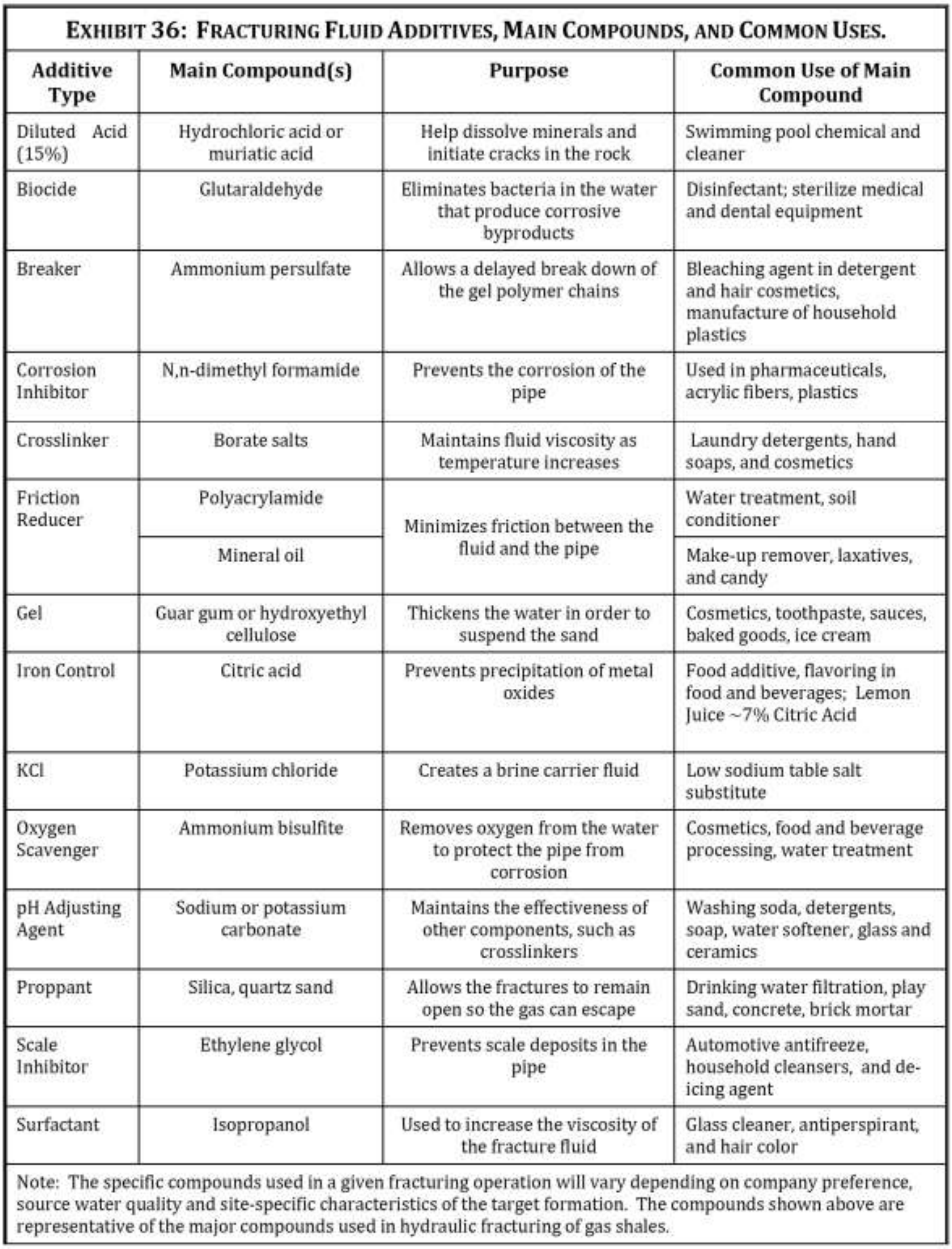


EXHIBIT 36: FRACTURING FLUID ADDITIVES, MAIN COMPOUNDS, AND COMMON USES.

Additive Type	Main Compound(s)	Purpose	Common Use of Main Compound
Diluted Acid (15%)	Hydrochloric acid or muriatic acid	Help dissolve minerals and initiate cracks in the rock	Swimming pool chemical and cleaner
Biocide	Glutaraldehyde	Eliminates bacteria in the water that produce corrosive byproducts	Disinfectant; sterilize medical and dental equipment
Breaker	Ammonium persulfate	Allows a delayed break down of the gel polymer chains	Bleaching agent in detergent and hair cosmetics, manufacture of household plastics
Corrosion Inhibitor	N,n-dimethyl formamide	Prevents the corrosion of the pipe	Used in pharmaceuticals, acrylic fibers, plastics
Crosslinker	Borate salts	Maintains fluid viscosity as temperature increases	Laundry detergents, hand soaps, and cosmetics
Friction Reducer	Polyacrylamide	Minimizes friction between the fluid and the pipe	Water treatment, soil conditioner
	Mineral oil		Make-up remover, laxatives, and candy
Gel	Guar gum or hydroxyethyl cellulose	Thickens the water in order to suspend the sand	Cosmetics, toothpaste, sauces, baked goods, ice cream
Iron Control	Citric acid	Prevents precipitation of metal oxides	Food additive, flavoring in food and beverages; Lemon Juice ~7% Citric Acid
KCl	Potassium chloride	Creates a brine carrier fluid	Low sodium table salt substitute
Oxygen Scavenger	Ammonium bisulfite	Removes oxygen from the water to protect the pipe from corrosion	Cosmetics, food and beverage processing, water treatment
pH Adjusting Agent	Sodium or potassium carbonate	Maintains the effectiveness of other components, such as crosslinkers	Washing soda, detergents, soap, water softener, glass and ceramics
Proppant	Silica, quartz sand	Allows the fractures to remain open so the gas can escape	Drinking water filtration, play sand, concrete, brick mortar
Scale Inhibitor	Ethylene glycol	Prevents scale deposits in the pipe	Automotive antifreeze, household cleansers, and de-icing agent
Surfactant	Isopropanol	Used to increase the viscosity of the fracture fluid	Glass cleaner, antiperspirant, and hair color

Note: The specific compounds used in a given fracturing operation will vary depending on company preference, source water quality and site-specific characteristics of the target formation. The compounds shown above are representative of the major compounds used in hydraulic fracturing of gas shales.

Figure 9. A summary of additives used in fracking, including examples of common usage. Source: Department of Energy (USA), 2009.

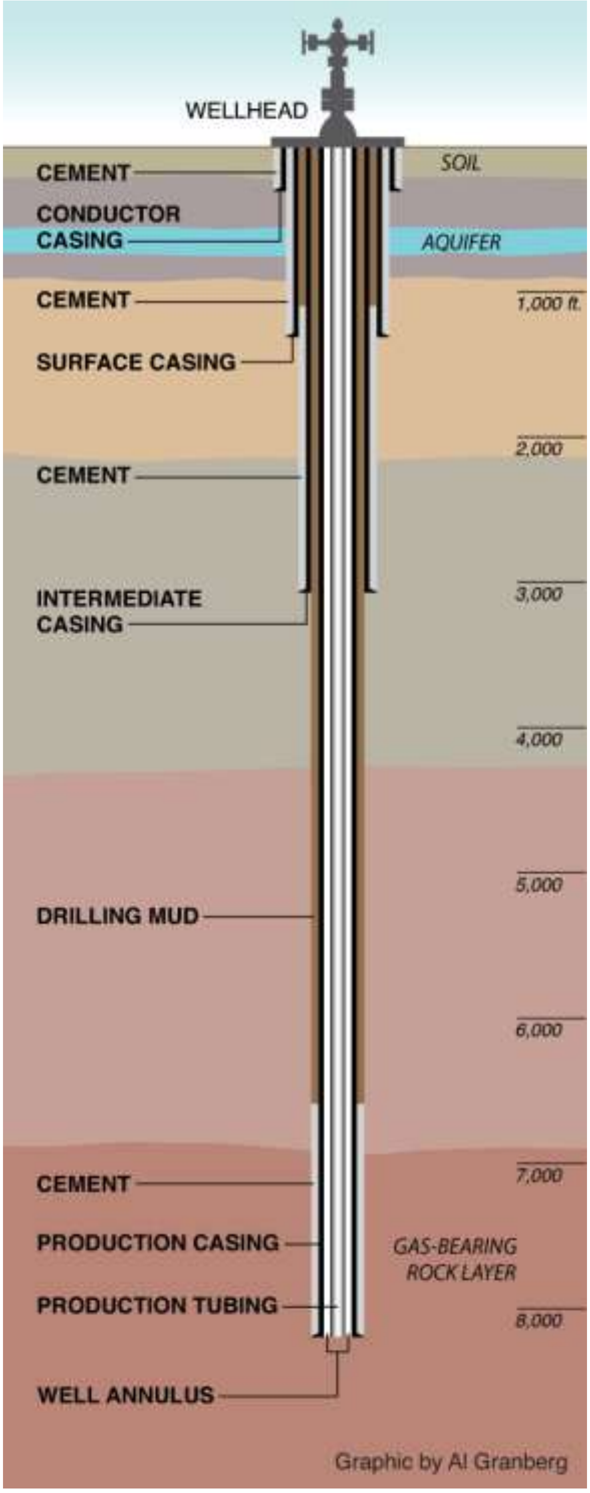


Figure 10. Schematic overview of a typical shale gas well showing the configuration of casing pipes and cemented intervals. Note that many shale gas wells are deviated from the vertical into near horizontal orientations as they enter the targeted shale strata. Ground water aquifers are typically located in the shallow subsurface, whereas shale gas reservoirs are located much deeper. The integrity of the casing and adjacent cement is critical in preventing contamination of ground water with drilling mud, fracking fluid, or released natural gas.

Source: ProPublica.

Drill site logistics

Developing a shale gas prospect by fracking typically involves repeated drilling over a wide area, often on a grid pattern. The efficiency of repeatedly fracking a single well bore follows a law of diminishing returns as the rock volume surrounding the base of well is effectively drained of gas. Fracking operations to date have spanned a wide range of time intervals, from several days to many years (MIT, 2011). In part, this depends on the geology of the shale gas formation and the relative efficiency of the fracking process. One approach is to systematically drill out the whole prospect by moving the rig to a new site and fracking repeatedly at new locations. Some of this movement could be reduced by multipad wells i.e. boreholes drilled in different directions and possibly to different depths from the same well head infrastructure. While there may be relatively few active drill sites at any one time, the overall environmental impact of a sustained and mobile drilling programme over a number of years needs to be carefully assessed.

Regulatory Approaches in Other Countries

In the notes that follow, the status of fracking is described in relation to onshore drilling activity. There is no evidence to suggest that fracking in offshore wells is prohibited anywhere.

Europe

Potential sites for shale gas extraction (and fracking) occur across Europe, with Poland, France and Norway estimated to have the largest accumulations.

In the UK, fracking is currently suspended as a consequence of two small earthquakes related to a fracking event near Blackpool in the Spring of 2011. This is a voluntary suspension by the operator of the Preese Hall-1 well in the Bowland Basin (Lancashire), Cuadrilla Resources. There is no government ban on fracking. The current UK government is broadly supportive of shale gas extraction through fracking, and believes that it can be safe ‘if done properly’ (BBC, 2011) and that ‘any risks that do arise are related to the integrity of the well, and are no different to issues encountered when exploring for hydrocarbons in conventional geological formations’ (DECC, 2011). With reference to flow back fluid, the UK Environment Agency believes that all appropriate legislation is already in place (House of Commons Energy & Climate Change Committee, 2011).

The Government of France banned fracking in May 2011 in response to pressure from environmental groups – i.e. not in response to any tangible incident in France or elsewhere involving leakage or contamination from a fracking program. In this case, exploration permits were revoked for three companies who admitted that fracking formed part of their appraisal plans. Note that exploration for, or development of, shale gas itself is not restricted; just the fracking process. Interestingly, fracking has formed an integral part of the development of geothermal energy from hot dry rock at the Soultz-sous-Forêts site in the Vosges, France (Soultz-sous-Forêts). Extraction of heat from the granite host rock is achieved by exchange with through going water pumped from the surface, and improvements in permeability have been achieved through fracking (including the use of acid additives). This is one of several examples of fracking activity unrelated to shale gas which generally passes unnoticed by the media. Other examples include the routine use of the process in offshore hydrocarbon fields. It is unclear whether the ban on fracking in France extends to these other situations.

Elsewhere in Europe, Poland has the largest reserves of shale gas and is set to embark on an extensive drilling (and fracking) programme (The Economist, 2011). The UK is actively monitoring the situation in Poland, and has cautioned against EU member states adopting a unilateral development policy driven by energy security (House of Commons Energy & Climate Change Committee, 2011). Poland has no specific shale gas legislation, and has recently granted over 100 concessions to mainly foreign companies. Bulgaria has granted exploration licences for shale gas to a major operator (Chevron) but then outlawed fracking (UPI, 2012). Germany also has large reserves of shale gas, and exploratory drilling is underway. Licences have been granted to Exxon, Wintershall and GdF, among others. Germany now has a legal commitment to remove nuclear power from its base load energy supply, and shale gas provides an opportunity to increase energy security. However, the ruling CDU government may legislate to make shale gas unattractive to investors (Centre for Eastern Studies, 2011).

There is a new European Union Technical Working Group on the regulation of shale gas extraction[1]. The purpose of this new group is to initiate an exchange of views and information and focusing in particular on the state of play with regard to shale gas activities across the EU, the technical knowledge on potential environmental risks and impacts, the environmental legislation applicable at EU and national level, as well as identified best practices at technological and administrative level. Their aim is to contribute to the European Commission's efforts to assess whether the existing EU environmental legislation ensures an appropriate level of protection to the environment and to humans. There is also the Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR), which aims to provide opinions on emerging or newly-identified health and environmental risks and on broad, complex or multidisciplinary issues requiring a comprehensive assessment of risks to consumer safety or public health and related issues not covered by other European risk assessment bodies. In addition, existing EU directives regarding Mining Waste and the Water Framework contain strict guidelines which can be applied to fracking operations in member states.

North America

In the US, both exploration and production of shale gas are fully underway, encouraged by deregulation in 2005. Subsequently, US gas prices have fallen in response to increased domestic production. The widespread use of fracking to extract shale gas has been central to this expansion of the gas market. The key federal level authority in the US for regulating fracking is the Environmental Protection Agency (EPA), aided by the Bureau of Land

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[1] Technical Working Group on Environmental Aspects of Unconventional Fossil Fuels, in particular Shale Gas.

Management (BLM) on federally owned land, and the US Forest Service. Many federal laws are actually implemented and enforced by state level agencies. The relevant federal laws are the Clean Water Act, the Clean Air Act, the Safe Drinking Water Act and the Oil Pollution Act. As described above, there have been few documented instances of ground water contamination, well head blow outs and surface contamination in the US, although these must be weighed against a background of many thousands of wells drilled and fracked over several decades. The Federal EPA is producing a preliminary report regarding the potential impacts on drinking water, due to be published later in 2012, with the full report due in 2014. Since 2005, the Safe Drinking Water Act contains an exemption for natural gas drilling, and companies do not have to disclose the chemical composition of the additives used in their fracking programmes (EPA (USA), 2011). However, the states of New York and New Jersey have suspended fracking operations in their jurisdictions in response to public pressure. In contrast, Texas and Colorado have implemented new regulations requiring disclosure of chemical additives used in fracking operations. Shale gas is also being developed in Canada, and concerns have been raised about the potential environmental impacts (CBC News, 2011). The regulation of fracking is again split between the federal and provincial governments. Alberta is conducting a review into fracking procedures and their potential impacts, and the state has ordered further scientific reviews.

Asia, Australia & Africa

Shale gas prospects are being evaluated in South Australia, Western Australia and the Northern Territory. These locations are far from population centres and impacts are expected to be minimal. Fracking is currently suspended in eastern New South Wales. In China, exploration is underway with shale gas blocks on offer from the government. However, the cost of producing conventional natural gas is very cheap here, and shale gas remains financially unattractive to investors or developers. India has huge potential for shale gas, with several large onshore sedimentary basins, but there are no reports of fracking activity at this time. Sasol is looking at shale gas prospects in the Karoo desert in South Africa, but the government has imposed a moratorium on fracking in response to pressure from environmental groups.

Establishing Best Environmental Practice

The following recommendations are based on experiences to date from around the world, and have been culled from the material discussed above and the publications listed in the bibliography. This is not intended as an exhaustive list, but can form the basis for a more comprehensive Best Practice document.

Monitoring and Assessment

- National or local environmental agencies charged with monitoring the potential impacts of fracking in the exploration and production of shale gas should be fully funded and equipped to carry out the necessary tasks. In particular, if an agency is to approve or licence the use of a specific chemical additive, it must have the means in place to detect and monitor the presence and movement of this chemical in local water supplies.
- From the data currently available, it would appear that while the mechanical fracking process itself does not pose a significant environmental risk, there are potential risks to ground water from poor well design or construction, especially in relation to the casings and the cements (SEAB, 2011a). Agencies need the resources and legal basis to investigate, analyse, approve or challenge the well designs and implementations used in the exploitation of shale gas. Operators must conduct thorough testing of well casing and cement prior to injection of fracking of fluids.
- Baseline monitoring studies of ground water are needed before any drilling activity begins.
- Open, simple and rapid communication of all regulations, incidents and best practice would help to combat misinformation from vested interests (SEAB, 2011b).

Materials and Resources

- Companies or agencies planning to use fracking should openly declare the exact chemical composition of the additives in the injected fluid, their volumes and their concentrations.
- Cementation of well bore casings should be carried out to the surface, followed by down hole pressure measurements and casing integrity tests to ensure the security of shallow ground water.
- Sourcing the large volumes of water required to support sustained fracking operations requires active monitoring and planned management of water supplies.
- Active and regulated management of waste water from the fracking process is critical, as this fluid poses one of the greatest tangible risks to the environment. This flow back fluid could be legally classified as hazardous waste, and will need to be assessed in relation to the European Union Water Framework and/or Mining Waste Directives.
- To protect the atmosphere, operators must be required to minimise all emissions of methane or other compounds.

Further Research

- Research and development should continue into the viability of removing all toxic additives from fracking fluids. The possibility of additive free fracking fluids (i.e. just water and sand) should be explored, both from a research perspective and industry sponsored testing. How critical are these chemical additives to the fracking process? How risky are they in relation to the perceived benefits? New quantitative data are required to address these questions.
- Further research is needed into the treatment of flow back fluid, in particular a clearer understanding of those processes that work and those that don't. Such a study should include the quantification of risks and costs associated with the various options. So called 'green completions' can reduce the emission of volatile organic compounds (VOC) and capture potentially valuable gas, but more research is needed to define the range of possible methods.
- Better geological (in particular, geomechanical) understanding of the fracture networks produced by fracking operations is required, especially in more complex shale gas plays (e.g. Bowland Shale, UK). Many shale gas formations in North America have a relatively simple sub-horizontal structure, but those in Europe are often folded and faulted on a variety of scales (e.g. Jackson & Mulholland, 1993). The more complex geometry of the shale gas formations in Europe, especially those of Carboniferous age, is due to an extended history of geological deformation spanning 300 million years. The generation and interaction of newly formed hydraulic fractures with much older pre-existing fault and fracture zones, and tilted bedding planes, is very poorly understood in terms of the mechanics and the hydrogeology, and new research programmes are required to address these topics.
- Detailed geological site-specific surveys must be conducted prior to drilling.

Media Coverage and Public Debate

- Companies or agencies adopting a transparent approach to shale gas development should be encouraged and supported.
- Media, corporate, scientific and other publicly available material on shale gas development and fracking should be framed in a rational, coherent manner. Detailed, peer-reviewed analyses of the successes and failures of fracking are the way forward.
- Regulatory bodies may wish to consider the wider issues raised by fracking, including the public perception of risk and the intrinsic uncertainties involved in subsurface science and engineering.

Summary

Published peer-reviewed data suggest that there is a low and probably manageable risk to ground water from fracking, whereas the potential impacts on the atmosphere from associated methane emissions and the risks of increased seismicity are less well known. However, the total number of published, peer-reviewed scientific studies remains low, and it is therefore prudent to consider and research in detail the full range of possible risks from fracking operations, including their magnitudes and uncertainties, and the potential environmental impacts of these risks in the exploitation of shale gas. The published reports (MIT, 2011; University of Texas, 2012) and those due to be published by the US EPA, a new EU Working Group on Shale Gas Regulation, and the International Energy Agency, will together provide a richer and more robust foundation for informed decision making in Europe. Much of the coverage to date in the traditional media and on the World Wide Web is not peer-reviewed and is often misinformed. Critical evaluations of shale gas fracking and the potential impacts on the environment must be based on peer-reviewed, scientific analyses of quantitative data. Agencies responsible for regulating or monitoring the environmental impacts of shale gas development need to be at the forefront of this effort (SEAB, 2011a). The design of any national regulatory framework to protect the environment from hydraulic fracturing operations should start with the supranational European Union directives and recommendations from working groups in progress.

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