Weald Action Group

Everything you always wanted to know about ACIDISING

Paper prepared for the Weald Action Group (a strategic umbrella for community groups across the region)

Author Kathryn McWhirter with special thanks for their comments and input to Emily Mott, Professor Lawrence Dunne, Emeritus Professor David Smythe, Muriel Lord, Elizabeth Williams and many others (some of whom prefer not to be named)

Introduction

Finally we're all talking about shale gas and fracking.

And we are ignoring the threat quietly posed by other extreme forms of gas and oil exploration. It's time to broaden the discussion, and talk also about acidising, or acidisation.

Acidising, little understood outside the oil and gas industry, is coming to communities from Sussex and Surrey to Lincolnshire. Acidising poses its own threats, and is likely to lead on to fracking at a later stage.

Planners and councillors are already facing decisions on applications for acidisation, yet they don't, for the most part, understand the science and the risks, nor the likelihood of proliferation - the very large number of wells that could be drilled. The oil and gas industry seems to do its best to confuse, using obscure wording in planning applications. Planning applications may not mention acidising by name. 'Well stimulation' sounds relatively friendly. The application at Markwells Wood in Sussex by UKOG (UK Oil and gas) calls it 'a new non-massive fracking-based reservoir stimulation technology that does not involve massive hydraulic fracturing'!

Few studies have addressed the potential problems.

In the UK there is little regulation or oversight

Fracking is for shale. Acids are used to dissolve unyielding limestone or sandstone to make pathways for oil or gas flow. It's not new. But like fracking, acidisation is now planned on a far bigger scale, down long, horizontal wells, a great multiplicity of wells. Many co-additives are needed to make the acids work effectively – a greater concentration of chemicals than are used in fracking fluids for shale. Acids in question range from hydrochloric (for limestone) to the super-dangerous hydrofluoric (for sandstone). Acidising can be done at low pressure, or, like fracking shale, at major pressure that fractures rock. Not so long ago this would have been called an 'acid frack', but the government re-defined fracking in 2015 on the basis of the amount of fluid used rather than rock-cracking pressure.

If it's not officially fracking, none of the new rules and regulations developed by government under oil and gas industry guidance will apply – so oil companies will feel free to drill and acidise in National Parks, Sites of Special Scientific Interest, Areas of Outstanding Natural Beauty and so on, at depths of less than 1,000 metres, without any of the baseline monitoring prescribed for fracking…

'Acid fracking' is not the only expression government and industry are keen to avoid in their attempt to make this extreme form of oil and gas extraction a non-issue for public, planners and press. There is also a game of words around the terms 'conventional' and 'unconventional'. There are no statutory definitions for these terms. Geologists and engineers use the term 'conventional' to describe a geological formation from which oil or gas flows easily. 'Conventional' formations are permeable, so that one well can drain the rocks over a wide area. In 'unconventional' formations, the oil or gas remains trapped in minute globules in the rock until 'stimulated' or released, by fracking, acidising or other means. 'Unconventional' formations are also known as 'tight' formations. At Balcombe and Horse Hill, for example, in Sussex and Surrey, the micrite limestone is 'tight' and 'unconventional'.

Yet the government declared all the PEDLs across the Weald to be 'conventional' when the announcement of the 14th round of new petroleum exploration and development licences was buried in the Christmas wrapping paper of 2015. Meanwhile, oil and gas companies call their 'prospects' in the Weald 'unconventional' when talking to potential shareholders, but imply that they are 'conventional' when speaking to local communities.

Most of the negative arguments against fracking can also be made against acidisation – plus many more for 'stimulation' with hydrofluoric acid, one of the earth's most dangerous chemicals. UKOG CEO Stephen Sanderson has explained to shareholders that acidised wells would, like high-volume hydraulically fracked wells, need to be 'back to back' at regular intervals across the Weald to access as much as possible of the oil – since the oil will flow only from the 'stimulated' parts of the rock near the wellbore. This proliferation of wells, industrialisation of the countryside, is one of the main reasons to oppose unconventional drilling. As with fracking for shale gas, there are implications for human and animal health, environment and climate. Chemical use is even greater in acidisation than in hydraulic fracking. Solid and liquid waste will be toxic, highly saline and radioactive, a risk to groundwater, surface water and soil should accidents occur. There will be potentially carcinogenic air pollution from flares, potential groundwater pollution via faults, fractures and the well bore, noise and light pollution, traffic, the risk of spills and other accidents. Storm and floodwater may spread pollution. Wells may be acidised repeatedly. There is little research on the subject of repeated acidisation and the cumulative effect on our environment and human health. On-site workers and local communities are particularly at risk. Significantly, Portsmouth Water, the CPRE and the local Environment Agency objected to UKOG's application to drill and acidise at Markwells Wood, West Sussex.

Fracking seemed enough to get our heads around. But the general public, campaigners, planners, water companies, politicians and regulators now all need to put acid on their agenda.

They should also think critically ahead and understand that, although initial planning applications may seek to acidise at below fracturing pressure, production stage will almost certainly require acidisation at pressure sufficient to fracture the rock.

The following is a detailed study of acidising, based on scientific papers, industry training manuals, promotional literature for new, patented technologies, and discussions with engineers, geologists and scientists. It has been informally 'peer reviewed' and declared 'scientifically literate'! But all comments are most welcome.

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Acidising, or acidisation

Acidisation is one of several techniques used to release 'tight' oil and gas – oil and gas that trapped in the tiniest droplets within rocks and unable to flow out at commercial rates unless 'stimulated' by fracking and/or acidising.

Almost two-thirds of the world's remaining oil reserves lie trapped in 'tight carbonate reservoirs' – strata that are rich in limestone (calcium carbonate) or dolomite (calcium magnesium carbonate). The Weald Basin across South East England contains tight oil with seams of carbonate. Oil migrated long ago from the shale below into the carbonate, where it remained trapped by a ceiling of shale above. The carbonate was then compressed by increasing layers of rock above so that pores and cracks in the rock shrank and tightened, no longer allowing the oil to move around.

While shale is seriously impermeable and must be cracked apart (fracked, hydraulically fractured) by high-pressure water to release its oil, many carbonate formations can be made to flow by dissolving pathways through the rock using acid solutions, sometimes under pressure strong enough to fracture the rock, sometimes not. Sandstone that fails to flow sufficiently can also be acidised.

According to the training pages of *Rigzone*, an online information service for the oil and gas industry worldwide, 'Acidizing the well is employed to improve permeability and production rates of tight gas formations. Acidisation involves pumping the well with acids that dissolve the limestone, dolomite and calcite cement between the sediment grains of the reservoir rocks. This form of production stimulation helps to reinvigorate permeability by reestablishing the natural fissures that were present in the formation before compaction and cementation.'

From acid wash to acid frack

Companies applying for planning permission to acidise may not choose to explain exactly where their plans might lie on the following rising scale of acidising severity. There are causes for concern at each level (acid use, other chemical additives, transportation, health hazards for workers, communities and environment…). Planners and concerned communities should ask companies to clarify exactly what they intend, and to specify whether they will be acidising at a pressure sufficient to fracture the rock.

1) ***Acid washing/acid maintenance*** is cleaning the well at low pressure, usually with a weak hydrochloric acid solution plus additives, to get rid of debris, rust or scale.

2) ***Matrix acidising*** is a more invasive operation, generally used in more permeable rock to free up the immediate surrounds of the well, to clear blockages and allow the oil to flow. It is used amongst other things to remove from the rock a film of the 'drilling mud' used to lubricate and cool the drill

and help return chippings to the surface. 'Matrix' means the environment close to the well. It is done at low or lowish pressure (below the pressure at which that particular geological location or 'formation' would fracture – this will vary depending on local conditions). The acid solution would typically penetrate between 1 and 5ft (30 to 150cm) into the surrounding rock, but sometimes in carbonate-rich rock it could travel 20ft (around 6m), creating small channels known as 'wormholes'. Higher concentrations of acid are used for matrix acidising than for acid washing or an acid frack – the solution would typically contain 18 per cent of chemicals, 15 per cent of which would be acid. Sandstone is much harder to dissolve, and matrix acidising of sandstone would affect a smaller diameter from the well , maybe 1 to 2ft (0.3 to 0.6 of a metre). In sandstone, the plan may be to dissolve particles of clay, feldspar or quartz within the sandstone to make or improve pathways for oil or gas. It is hard to believe that matrix acidising would make sufficient difference in a seriously 'tight formation' – but it would be enough at flow-testing stage to give companies an idea of how well a formation might flow if later acid fracked.

3) ***Fracture acidising/acid fracking/acid fracturing*** – this is a major operation, for less permeable rock, usually carbonate, done at a pressure above the fracture point of the rock, and using considerably more chemicals that matrix acidising, and considerably more than in hydraulic fracturing of shale. Frack fluid for shale may be 99.5 per cent water. An acid frack solution will typically contain 17 per cent of chemicals, according to Khadeeja Saba Abdullah of the University of California, Los Angeles: perhaps 8 per cent acid, 9 per cent other additives. Acid fracking, she says, uses more water than matrix or maintenance acidising, maybe as much as 700,000kg per treatment. The aim is to dissolve the rock or components of the rock with some force, and penetrate much further into the formation. Length of fractures would typically be 50 to 100 feet (15 to 30 metres), in exceptional cases a few hundred feet (maybe 100 metres). So acid fracking (like fracking shale) requires a multiplicity of wells if a company wants to reach all parts of its licenced area. According to Schlumberger (a leading provider of technology to the oil and gas industry): 'Acid fracturing is a hydraulic fracturing treatment performed in carbonate formations. The objective is to 'etch' the open faces of induced fractures using a hydrochloric acid treatment. When the treatment is complete and the fracture closes, the etched surfaces provide high-conductivity flow paths from the reservoir to the wellbore.' Because 'etched' by the acid, acidised fractures in carbonate formations do not need to be held open with 'proppants' such as

sand. The process may need to be repeated, many times over, to keep the well flowing. The formation may be pre-treated with gels – see below.

Different rocks, different acids, or mixes of acids

Put over-simply, hydrochloric acid is used on carbonate formations, hydrofluoric acid on sandstone formations.

But geological formations are unlikely to be pure carbonate or pure sandstone. They may be mixed with clay, quartz, impurities various. And combinations of acids sometimes work better than one alone. So on a carbonate-rich formation, hydrochloric acid may be supplemented with sulphuric acid and/or organic acids: citric acid, formic acid or acetic acid. On sandstone the main acid used is hydrofluoric acid but this is often used in combination with hydrochloric acid – the mix known as 'mud acid'. Acidising sandstone 'formations' with hydrofluoric acid is not guaranteed success – one industry training manual suggests companies might expect an increase in flow of oil or gas in only a quarter or half of wells acidised with hydrofluoric acid. A hydrofluoric acid 'job' might give rise to precipitates that block the pores or fractures in the rock, especially when a lot of clay or more than ten per cent of carbonate is present in the sandstone. Pre-flushing with hydrochloric acid can pre-empt this problem. The proportion of acids used and the strengths depend partly on the temperature at the bottom of the well – it's hot down there! At 'low' 'bottom hole' temperatures – below 93°C, acids can penetrate deeper.

Hydrofluoric acid – potentially catastrophic

Hydrofluoric acid is one of the most dangerous chemicals on earth. Undergraduate students are not allowed to use it in the lab. Its use presents a high risk for site workers, chemical workers and drivers, and for nearby communities, should there be an accident or blowout.

But there is little track record of use of hydrofluoric acid in the oil industry in the UK. In July 2016 the Environment Agency replied to a Freedom of Information Request from Helz Cuppleditch of Sussex as to 'how many onshore hydrocarbon (oil or gas) exploration and/or production sites under your jurisdiction have used hydrofluoric acid?' They admitted: 'The information you have requested is not held by the Environment Agency.'

When the British government was establishing 'Standard Rules' for onshore oil and gas planning applications – aspects and substances that could be nodded through planning without scrutiny – hydrofluoric acid was on the originally proposed list. It is thought that an intervention by Professor Lawrence Dunne, a resident of Balcombe, resulted in its being removed from the final Standard Rules. Hydrofluoric acid is now beginning to appear in planning applications – for example for use in the sandstone formation in Wressle, North Lincolnshire.

It is vital to ensure that no loopholes are created for the oil and gas industry around the use and transport of hydrofluoric acid.

In America the steel workers' union USW are campaigning to have the use of hydrofluoric acid banned in oil refineries. Their paper *A Risk Too Great* explains: 'If released into the atmosphere, hydrofluoric acid rapidly forms dense vapor clouds that hover near land and can travel great distances. Like other powerful acids, hydrofluoric can cause deep, severe burns and damage the eyes, skin, nose, throat and respiratory system. But the fluoride ion is also uniquely poisonous. Entering the body through a burn or by the lungs, it can cause internal damage throughout the body. At high enough exposures, HF can kill.'

Harvard University's *Guidelines for the Safe Use of Hydrofluoric Acid* goes into further detail on its toxic effects: 'Fluoride poisoning is associated with hypocalcemia (low calcium levels), hyperkalemia (high potassium levels), hypomagnesemia (low magnesium levels), and sudden death. Systemic hypocalcemia should be considered a risk whenever the body surface area of skin burns from concentrated HF exceed the size of the palm of your hand. Concentrated HF burns can be fatal if only 2% of the body surface area is exposed. .. HF contact with the eye can cause eye burns and destruction of the cornea. Blindness results from severe or untreated exposures… Inhalation of HF vapors may cause "laryngospasm, laryngeal edema, bronchospasm and/or acute pulmonary edema.' Initial symptoms of exposure include coughing, choking, chest tightness, chills, fever, and blue skin. Deep ulceration may lead to gangrene.

Hydrofluoric acid can be transported by road in specially constructed, dedicated tankers, or it can be made within the well by reacting fluorite with sulphuric acid. If hydrofluoric acid were transported on our busy roads and motorways, through densely populated towns and villages, accidents and spills could be catastrophic. The transportation of hydrofluoric acid is tightly regulated, with a standard warning code, but incidents are rare, so hospitals, fire crews and other emergency response teams would not necessarily know the implications. For instance, if the wrong chemicals were used to neutralise the acid, the consequences could be devastating for nearby people, animals and the environment generally. The topsoil would have to be removed to a hazardous waste landfill. One engineer commented: 'It's not the sort of load you want going down country lanes and having to reverse when it meets a Range Rover plus horse trailer coming the other way!'

Professor Dunne has many concerns about the use of hydrofluoric acid for oil exploration and production: 'The oil and gas industry has huge experience in this country of using hydrochloric acid,' he says, 'but hydrofluoric acid is in a different ballpark. What studies have been done to determine the radioactive flowback components from formations washed with hydrofluoric acid? Hydrofluoric acid is very different and much more potent that hydrochloric acid. Hydrofluoric acid will extract the radioactive uranium in the well as well as uranium hexafluoride in the returned acid wash. Both are lethal substances. How will they be dealt with? We know a great number of cancerous toxins enter the air through flaring, what are the implications for air pollution of a well having been acidised? What training will the well crews and the emergency services have in working with hydrofluoric acid and tackling accidents?'

Blowouts

This is a worst case scenario. A blowout involving hydrofluoric acid would be catastrophic for workers as well as for communities.

A 'blowout' is an out-of-control gushing-up of fluids and gases from a well after pressure-regulating systems have failed. Blowouts can happen at any stage from drilling onwards. 'Gushers' were a regular feature of oil and gas drilling until pressure control equipment began to be developed in the 1920s. They are rarer nowadays – modern wells have blowout preventers or BOPs, essentially large valves at the wellhead. But blowouts still happen. Deepwater Horizon in the Gulf of Mexico and the 2012 Elgin blowout in the North Sea are recent examples. As there are generally warning signs, human error or negligence is usually to blame. (Total were fined a measly £1.125m for their Elgin blowout, and most of the press called it a 'leak' – see below a link to a fascinating letter from an Elgin rig worker at the time of the Balcombe protests.) Professor Dunne has concerns over whether the material in the neck of a blow-out preventer would be resistant to attack from hydrofluoric acid. An accidental spark during a blowout can lead to a catastrophic oil or gas fire. Accident response teams sometimes *choose* to set fire to the escaping gases and fluids, especially if hydrogen sulphide is present, tossing up whether the escapee chemicals themselves are more toxic than their combustion products.

It's a fair guess that in April 2014, a blowout following a hydrochloric 'acid job' resulted in a cloud of nebulised hydrochloric acid near the village of Wittorf in Lower Saxony, North Germany. Exxon Mobil admitted that they had to flare off gas 'for technical reasons'. Local people reported a cloud of what looked like steam and 'terrible smells' around the Söhlingen Z5 well. People even a few kilometres away experienced breathing difficulties, coughing, headaches, red and streaming eyes, inflammation and bleeding pores, burning skin and general malaise. Some were treated in hospital. This was hydrochloric acid; hydrofluoric acid is many times more dangerous.

Is acidising new?

Oil and gas prospectors experimented with acidising in the late 19th century, but it was only in the 1930s that it became of practical use, when corrosion inhibitors were developed to prevent damage to metal well casings. Especially when hot, acid can attack well casings aggressively, and the deeper the well, the hotter it's likely to be at the bottom. Today 'acid jobs' are very widely used, initially on new wells to improve flow, and often repeatedly as yield decreases. (The acid solution may nowadays be pumped down a coiled tube inserted inside the well casing.)

What *is* new, since the mid-1990s is acidisation *in long lateral wells*. As with high volume hydraulic fracturing (the now famous and infamous fracking of shale formations) there has been *a change of scale* – like the difference, as oil and gas engineer Mike Hill says, between a corner shop and a hypermarket. Since the advent of horizontal drilling, oil and gas companies are now able to 'get up close', at great length, to a much higher proportion of a target formation.

Investigating individual wells around Britain, it is not always clear where and how much acidising has been used in the past – including 'conventional' wells. Regulators have so far offered no stats.

Is acidising 'conventional'?

Geologists and the oil and gas industry use these terms to distinguish *geological formations* targeted for oil and gas production. Whether the formations are classified as conventional or unconventional depends on the ease with which oil and gas flow through them. If a formation needs 'stimulating', with frack fluid or acid, it is unconventional.

In recent times, however, the terms conventional and unconventional have been loosely applied to *techniques*, such as fracking, acidising, underground coal gasification and the extraction of coal bed methane and well as to the 'conventional gas' or 'unconventional oil' that might result.

In conventional formations, oil or gas migrate upwards or sometimes laterally until either they reach the surface or become trapped under impermeable rocks, often in a dome or fault above or alongside porous 'reservoirs'. Once a well is drilled, ideally into the 'dome', the oil or gas can flow through the permeable, porous rock and up the well at a commercially viable rate. Formations that do not flow easily are known as 'tight', and 'unconventional'. The Upper Jurassic carbonate strata of the Weald (such as the micrite at Balcombe and Broadbridge Heath) is highly unlikely to flow at an economic rate without 'stimulation' (acidising and/or fracking). These formations are unconventional. So are the sandstones of North Lincolnshire, for example in Wressle, where poor permeability will not allow the gas to flow without stimulation.

The situation is less clear in the Weald in wells drilled into the deeper, oolite limestone. This was laid down in the Lower Jurassic period, long before the micrite. Oolitic limestone is composed of tiny spherical 'ooliths' formed when calcium carbonate precipitated around grains of sand in warm lime-rich seas. Imagine marbles in a jar – there will always be spaces between them. So in ooltic limestone, even though some bits of loose lime may have welded up some of the gaps, the beds are likely to allow fluids or gases to flow. The historic, 'conventional' wells of the Weald, Singleton, Horndean and the like, drilled into 'sweet spots' in the oolite, have always been considered 'conventional'. Elsewhere, however, the oolite may be 'naturally cemented' – the spaces more or less completely bunged up.

When the Government allocated its 14th round of Petroleum Exploration & Development Licences in 2015, all the licenced areas across the Weald were officially labelled in the spreadsheet as 'conventional'. UKOG, who drilled the so-called 'Gatwick Gusher' into the micrite at Horse Hill in 2016, insist to the public that the well is conventional but talk of 'unconventional plays' to their shareholders. This appears to be a semantic game to make the looming large-scale oil exploration across the Weald appear to be cosy, old-fashioned, and nothing whatsoever to worry about. Whether acidisation has been used for decades is irrelevant. The objective across much of the Weald is to extract oil from tight, unconventional formations.

Getting the measure of tight oil and gas

Oil flow through rock (the formation's permeability) is measured in darcies and millidarcies. (French water engineer Henry Darcy may be turning in his 19th century grave.) A conventional (easy-flow) formation has a permeability of between 0.01 and 0.5 darcy, while an unconventional formation would be down in the millidarcy or microdarcy range. *Rigzone* helpfully explains that 'a darcy is the permeability that will allow a flow of 1 cubic centimeter per second of a fluid with 1 centipoise viscosity (resistance to flow) through a distance of 1 centimeter through an area of 1 square centimeter under a differential pressure of 1 atmosphere.' Mr Darcy was not just a handsome chap.

It is important to distinguish between porosity and permeability. A formation can be porous but not permeable. To be permeable, liquids and gases need to be able to flow, through pores, fissures or 'joints'. Take the Kimmeridge micrite, the target of Cuadrilla and UKOG in Balcombe and Horse Hill. Micrite is an extremely fine-grained limestone made up of minute algal remains whose pore spaces are 'less than a tenth of a sand grain' in size. In Balcombe and Horse Hill these tiny pores are filled with oil. The micrite is very porous, but because the pores are so small and poorly interconnected, the permeability of the micrite is low.

According to geologist Dr Ian West of Southampton University, 'Porosity is the percentage of pore space. Permeability is the extent to which fluids can flow through the rock. If the pores are very small, in spite of good porosity, then the fluids cannot flow easily. Conventional production of oil or gas involves flow of fluids through large interconnected pores. Unconventional production opens up spaces for the fluids to flow when the permeability is very low because of the minute sizes and lack of connection of the pores.'

In the olden days, he says, fine-textured rocks of low permeability, their pores often blocked by flakes of clay, were not used for oil and gas production. When Conoco drilled and acidised the well now called Balcombe 1 in the mid-80s, it failed to flow in commercial quantities. Cuadrilla have yet to return to acidise and test-flow Balcombe 2 with its long, horizontal bore.

How much acid?

It depends on the situation and the objective. New, gel-based technologies can reduce the amount of fluid used (see below). Hydrochloric acid could be used at up to 28% but typically up to 15% concentration, hydrofluoric acid at much lower concentrations, 0.5 to 3%. Recent planning applications have chosen vocabulary such as ‘low volume’ and ‘non-massive’, presumably eager to fit within the government’s new definition of fracking in the Infrastructure Act. Fracking is now legally defined by the amount of water used (over 10,000 cubic metres per well, over 1,000 cubic metres for each section), whereas *as any fule kno* fracking is more about pressure than volume – the pressure at which the fluid fractures that particular rock formation.

What happens to the acid underground?

In carbonate formations, hydrochloric acid reacts quickly with the rock to form salt, water and carbon dioxide.

In sandstone, the reaction with hydrofluoric acid is more complex. According to The American Petroleum Institute, the reactions happen in three stages: ‘In the primary stage, the mud acid reacts with the sand, feldspar and clays to form silicon fluorides and aluminum fluorides. In the secondary stage the silicon fluorides can react with clay and feldspar to release aluminum and silicon precipitates, however with proper design, formation of these damaging precipitates, which can restrict flow of oil or gas through the formation, can be avoided. In the final stage the remaining aluminum fluorides react until all the remaining acid is consumed.’

Flowback

Most of the acid is consumed down in the rock. But care has to be taken with the flowback water from an ‘acid job’.

The American Petroleum Institute again: ‘After the acid job is successfully pumped and the well is brought to production, the operator should consider using separate tanks or containers to isolate the initial produced fluids (spent acid and produced water). The fluids that are initially recovered will contain the spent acid (acid that is largely chemically reacted, neutralized, and converted to inert materials) and it will typically have a pH of 2-3 or greater, approaching neutral pH. These fluids can be further neutralized to a pH>4.5 prior to introduction into the produced water treatment equipment, if necessary. Once neutralized, the spent acid and produced water can be handled with other produced water at the production site. Most produced water, including spent acid, is treated as needed and then injected via deep injection wells that are permitted by the jurisdictional regulatory authority.’

As with flowback from shale fracking, the flowback from an 'acid job' will contain not only chemicals and reaction products of chemicals injected in the treatment fluid but also substances released from the formation: brine, salts of heavy metals, radioactive materials (uranium as well as uranium hexafluoride in the case of a hydrofluoric acid 'job'). As with shale fracking, it will be a big headache disposing of this flowback and 'produced water' (produced water is contaminated water released from the formation, which in practice is mixed in with the flowback, at least in the early stages). Treatment of this liquid waste is difficult and costly, so likely solutions are a) mixing it with other effluent so that the levels of contaminants in the final mix fall below levels considered toxic, and then dumping the mix at sea; or b) injecting it into wells, either specially drilled or pre-used as production or exploration wells. The industry claims that it will send the waste fluids fi

There are states in America suffering a high earthquake rate because of injection of fracking waste. Oklahoma used to have two earthquakes per year; now it has more than two per day. At Markwells Wood in West Sussex, the current application is for an injection well in addition to four horizontal wells for exploration/extraction. Markwells Wood is in a highly faulted zone not far from Chichester, which has, in the past, suffered earthquakes. Eight fault lines cross through the site and the major Bembridge Saint Valery fault line is close.

Maximising the economic recovery…

Acidising fluids will follow the path of least resistance, not necessarily the direction desired by the engineers. That may mean that the least permeable area doesn't get its fair share of the acid. Acid solution going astray is called 'leakoff'. Leakoff is avoided in various ways. Making the acid mix viscous slows the flow (see 'Other additives', below). Temporary plugs can be engineered into place. This is harder to do in long lateral wells. Chemical additives can also do the trick (see below). To avoid damage to the well casings by acid, coiled tubing is sometimes used down and along the wellbore to deliver the acid, and this can also help target particular sections of long, lateral wells. There are also newer technologies, gels and 'fishbones' (see below).

Another potential problem is the creation of insoluble substances as a result of reactions between acids and constituents of the formation. These may block the pores and 'wormholes' in the rock, undoing the 'good' work of the acid or even making matters worse than before the acidising took place. Sludges or emulsions may form if acid comes into contact with oil or other well fluids such as drilling muds. Additives are the answer.

Other additives

Many other chemicals may be added to an acid wash to avoid problems and maximise efficiency, the type and volume based on analysis of cores of rock taken while drilling, and then lab tests. Because the challenges are different in carbonate or sandstone formations and shale, the chemicals vary too. Some additives commonly used in frack fluids for shale may also be unsuitable for an acidic environment. As with frack fluids for shale, acidising additives are sometimes mixed in anonymous proprietary brands.

Listed here are some of the groups of additives:

- Various polymers (long chains of molecules that create a gooey, viscous texture) may be added, sometimes along with metallic salts, to increase the viscosity and slow the flow of the acid wash. According to PetroWiki: 'Acids may be thickened for diversion during acidizing with soluble polymers such as xanthan gum (a biopolymer) or acrylamide polymers. Higher viscosity may be obtained with crosslinking metal ions or ligands. Certain surfactants may be used to thicken acid through the formation of surfactant micelles.' (See below for further details and explanations.)

- Whatever the acid, corrosion inhibitors are needed to reduce damage by the acid solution to the well casings and other equipment both at the surface and in the well. Inhibitors are typically organic compounds that cling in a thin film onto metal surfaces. They are expensive but indispensable, although not 100 per cent effective.

- Chemicals may be added to deter 'leakoff' as an alternative to physical barriers (see 'Maximising the economic recovery…' above). Schlumberger propose the following: '…chemical diversion methods include nitrogen foam, bridging agents such as benzoic acid flakes, and cross linked polymer gels. These create a temporary plug in high-permeability carbonate zones so that the stimulation fluids are diverted into the low-permeability zones that require more treatment.' In gas wells, 'foamed acid' may be the best option as other additives may be difficult to clean out of the formation. (See 'gels' below for an explanation of cross-linking.)

- Detergents/surfactants/anti-sludge agents/solvents are needed to avoid the formation of unwanted gels, sludges and emulsions and prevent the added corrosion inhibitors from coating the rock formation.

- Iron control agents keep rust particles in solution (as ferric or ferrous ions). Iron and the compounds it forms are one of the big headaches in an 'acid job'. Iron reducing or iron complexing agents include erythorbic acid, citric acid with acetic anhydride, and nitrotetraacetic acid.

- Hydrogen sulphide 'scavengers' in 'sour', sulphidy formations (as found in the Weald) remove hydrogen sulphide so that it cannot react with iron to form precipitates of iron sulphide.

- Calcium sulphate inhibitors are used in formations where high levels of sulphate ions are present in the water within the formation, or rock containing anhydrite. These are usually phosphonic acid or polyacrylate.

- Possibly acetic acid in a pre-flush to prevent precipitation of iron carbonate.

- Alcohol at between 10 and 20% may speed the return of fluids out of the formation and up to the surface. Methyl alcohol or isopropyl alcohol are sometimes used.

- Clay stabilising polymers may be needed if the acid fluid is likely to disturb and move clay particles or cause them to swell and block passageways. These could be polyquaternary amines, polyamines or cationic surfactants.

- Biocides deter bacterial growth.

- A hydrofluoric 'acid job' may be preceded by a hydrochloric or citric acid preflush to dissolve carbonate, and/or it may be followed by an 'overflush' of equal or greater volume than the main 'acid job' to clean out any remaining precipitates, fluids or other chemicals. *PetroWiki* (an info-sharing platform for the oil and gas industry developed by the Society of Petroleum Engineers, SPE) gives an idea of possible chemicals in an overflush after a hydrofluoric acid treatment: ammonium chloride brine, weak acid (3 to 7.5% HCl acid), filtered diesel oil or aromatic solvent (oil wells only) or nitrogen (gas wells only), ethylene glycol monobutyl ether (EGMBE) and a polyquarternary amine clay stabiliser.

Acid fracking is normally done without a proppant – the tiny particles injected with frack fluid when fracking shale to keep the fractures open. Proppants are usually a rare, spherical silica sand, or sometimes bauxite, or tiny aluminium oxide or ceramic beads. When fracking or working the 'matrix' or well surrounds with acid solution, the hope is that the pathways, wormholes and etched fractures will remain sufficiently open without the need for a proppant. If not, or if the 'acid job' does not result in an adequate flow, acid fracking may be followed by hydraulic fracturing.

Khadeeja Saba Abdullah, now Doctor of Environmental Science and Engineering, University of California, Los Angeles, focussed her dissertation in 2016 partly on this subject, concerned at how little was known about it given the increase in acidising in California over the past decade. Hers was the first study of the potential toxicological impact of acidisation. Similar chemical additives are used in acidising as are used in high volume hydraulic fracking of shale, she says, but the concentrations are much greater, and those used most frequently are different. 'There are close to 200 specific chemicals used in acidisation, with at least 28 of them being F graded hazardous chemicals. Some are used frequently in the range of 100 to 1,000 kg per treatment, such as hydrofluoric acid, xylene, diethylene glycol and ethyl benzene. Close to 90 more chemicals are identified using non-specific names as trade secrets or reported with no quantity. Unlike hydraulic fracturing, the chemical concentrations in acidising are high, ranging from 6% to 18%.'

These chemicals, she says, include neurotoxins, developmental or reproductive toxins, and carcinogens, and for many there is little understanding of their toxicity, the quantities used, and how much comes back in the flowback and produced water whether the original chemicals, products of underground reactions or substances leached out from the formation.

Two heads are better than one

According to PetroWiki: 'Long treatments can best be controlled by two persons—one to coordinate the acid schedule and rate and pressure control, and the other to check materials; titrate acid; and monitor volumes, rates, and pressures. The engineer who recommended and designed the job and the supervisor who prepared the well for acidizing make a good combination.'

New technologies - gels

Gels have been used in frack fluids for shale and in acidising fluids since the 1980s to make the liquids more viscous – this slows down the acid reaction, making it more effective, allows the acid mix to be targeted more precisely at particular sections of the formation, and can enable the fluid to block existing 'wormholes' and force it to make new ones. Gels are particularly useful in long, lateral wells, which are hard to acidise effectively with fast-flowing liquids. The R&D departments of companies such as Schlumberger and Halliburton have worked for decades on developing and improving gels and are still coming up with new proprietary brands with names such as Swellpac, Duofrac or Squeezefrac, some of which are now being proposed for use in Britain. Whether for matrix or fracture acidising, treatments are typically two-fold. Firstly a water-based gel mix (called a 'pad') is pumped into the well to swell and create fractures, and then the acid is pumped to etch the sides of the fractures. The acid fluid will also typically contain a gel, and may be referred to as a VCA or viscosity-controlled acid. Such gelled treatments can increase production enormously.

Gelling agents may be 'linear' (simple polymers made up of a chain of molecules), usually derived from plants such as guar gum (from a legume), carboxymethyl HPG (from wood), hydroxyethyl cellulose (from wood or other plants), or xanthan gum, a substance produced when a certain bacterium ferments sugars, producing gloop. Gelling agents come as powders that swell when mixed with water. Some are used in the food industry. Some gelling agents are 'cross-linked'. This means that a chemical, typically borate ions, is used to link one polymer chain to another, to form a three-dimensional shape that is more 'elastic' and better able to hold solids in suspension. The borate link is strong in the original acid solution, but breaks down once the acid reacts with the formation, so that the polymers return to simple chain formation and the mix no longer blocks the passageways. Another recent development, Clearfrac, is a 'visco-elastic surfactant' containing no polymer.

These are the kind of 'new techniques' that have been proposed by UKOG at Markwells Wood and Egdon in North Lincolnshire. The language in the planning applications is vague. At Markwells Wood, for instance, UKOG's planning application talks of *'utilizing horizontal wells and new non-massive fracking-based reservoir stimulation technology that does not involve massive hydraulic fracturing ("fracking").'* 'Massive' is a lesser-used industry term for high volume. Is it an acid frack? Is it a fishbone? Who can tell? (For fishbones, read on.)

The planning application at Wressle in North Lincolnshire (targeting sandstone) mentions a 'proppant squeeze'. Egdon Resources personnel, meanwhile, have name-dropped a proprietary brand called 'Duofrac' – much used in the USA in carbonate and sandstone wells, a gel and proppant mix, followed by gelled acid.

Texas fracking/acidising technology company EnerPol explain their pre-acidising mix 'SqueezeFrac' as follows:

1. *Small, solid particles of degradable polymer and proppant are pumped into the wellbore with water*

2. *Wait 2-6 hours for polymer to degrade to high-viscosity gel in wellbore (heat + water cause degradation)*
3. *Apply pressure at surface with small pump to "squeeze" high-viscosity gel (with suspended proppant) into formation (low velocity / high pressure)*
4. *Within 1-2 days polymer gel completely degrades leaving proppant in place and no residue on formation*

New technologies - Fishbones

Fishbones is the name of a Norwegian oil and gas technology company and the method it has developed for delivering an apparently super-targeted 'acid job' in carbonate, sandstone or coal bed methane. The company worked initially with Statoil, Eni, Lundin, Innovation Norway and the Research Council of Norway, and is now in league with ten major oil and gas companies including Total, Shell and BP. Into the well is inserted a tube incorporating valve holes (so that no in-situ perforation of the well lining by explosives is needed). Once the pipe is in place, 200 narrow-diameter 40ft/12m titanium needles jet out into the formation 'like the ribs of a fish skeleton', driven by turbines. At the tips are jet nozzles to deliver the frack fluid. According to the company, the equipment cuts fracking time from days to hours, uses ordinary rig pumps rather than banks of fracking pumps, and cuts water use. It was first field trialed in 2013 in a coalfield in south Sumatra, then in 2014 in carbonate in Texas, and in 2015 in tight sandstone in the Norwegian Sea.

Fracking or acidising, both to be resisted!

Whether industry chooses to call the micrite acidising process conventional or unconventional, fracking or not fracking, ancient or modern, acidised wells will need to be drilled 'back to back' across the Weald if companies are to exploit their PEDL areas to the full. ''You have to drill a lot of wells close to each other (…) almost back to back so that it becomes like an industrial process,' said Stephen Sanderson, CEO of UKOG (https://www.youtube.com/watch?v=5zBAD-EJHyk). You can almost see the thought bubble as he compares the Weald with the similar carbonate Bakken oil 'play' of North Dakota, which is fracked. Production from new wells is likely to slow rapidly, and the wells will need to be re-acidised, or new wells will have to be drilled. This would also be the case in 'tight', 'naturally cemented' oolite, contrasting with the historic 'conventional' wells of the Weald, which can draw from a large, permeable area and may flow for many years.

If things develop as the oil and gas industry desire, there will be hundreds of oil wells across the Weald; toxic, radioactive waste will be created, solid and liquid; and there will be all the local hazards and nuisances of fracking: noise and light pollution, air pollution, flares in early stages (with their dangerous emissions), traffic, the possibility of releasing treatment fluids or previously locked-in toxins into our water sources via the well bores, fractures or natural faults.

And the result will be 'extreme' fossil fuels, fuels that must stay in the ground if we are to avoid catastrophic climate change.

Acidising the Weald

The Weald basin stretches from Kent in the east into Hampshire in the west. Sediments deposited over the millennia have resulted in largely the same underlying layered geology across the region, limestones (calcium carbonate), sandstones, clays and mud rocks (shales), sometimes found at different depths because the earth moved and folded in millennia gone by. Some 70 million years ago, the rock strata were pushed and folded upwards in earth movements that also formed the Alps. In the Weald, the movement caused much crumpling and faulting. Emeritus Professor David Smythe has shown how these faults today could act as conduits for polluting liquids and gases (see below).

Organic-rich mudstone strata that at some stage have been buried deep and hot may have become 'thermally mature', and have generated oil within their hard, fine, fragile layers. Oil is most likely to be found within the shale in in a central long whale-shaped area lying west to east across the centre of the Weald map. Oil may be trapped in tiny particles in the shale, or it may at some point have migrated into limestone or sandstone strata above, only to be blocked there by a further ceiling of shale. Kimmeridge Limestones (Upper Jurassic period) are the oil companies' target in the central part of the Weald. These are unconventional strata, needing stimulation, by acid and/or fracking – as at Balcombe and Horse Hill. According to Southampton geologist Dr Ian West, 'Argillaceous coccolith micrites are not used as conventional reservoir rocks in general in southern England. Even if they have adequate porosity, the permeability in such a fine-grained rock would be remarkably low and unsatisfactory for normal reservoir purposes.'

Long ago, the Kimmeridge micrite cracked under the pressure of the rock above, and during earth movements. Now rock pressure keeps these natural fractures too tightly closed for oil to flow at a commercial rate. Above and below this clay/micrite seam is shale, cut through a little deeper down by a further band of Kimmeridge micrite. Producing from a low-permeability unconventional reservoir above oil shale in this way is known as 'hybrid production'.

The other carbonate 'prospect' in the Weald is the Great Oolite, a much deeper limestone sedimentary layer of the Middle Jurassic period. Oolite is made up of particles that are more spherical and less fine-grained than micrite, so that the rock is potentially, but not always, more permeable. Indeed, the Great Oolite is the main conventional oil reservoir across the Weald – the conventional wells at Singleton and Storrington, for instance, in West Sussex, are drilled into the Great Oolite. Great Oolite is the target at Markwells Wood in the South Downs National Park, West Sussex, over which a planning decision including acidisation is due in early 2017.

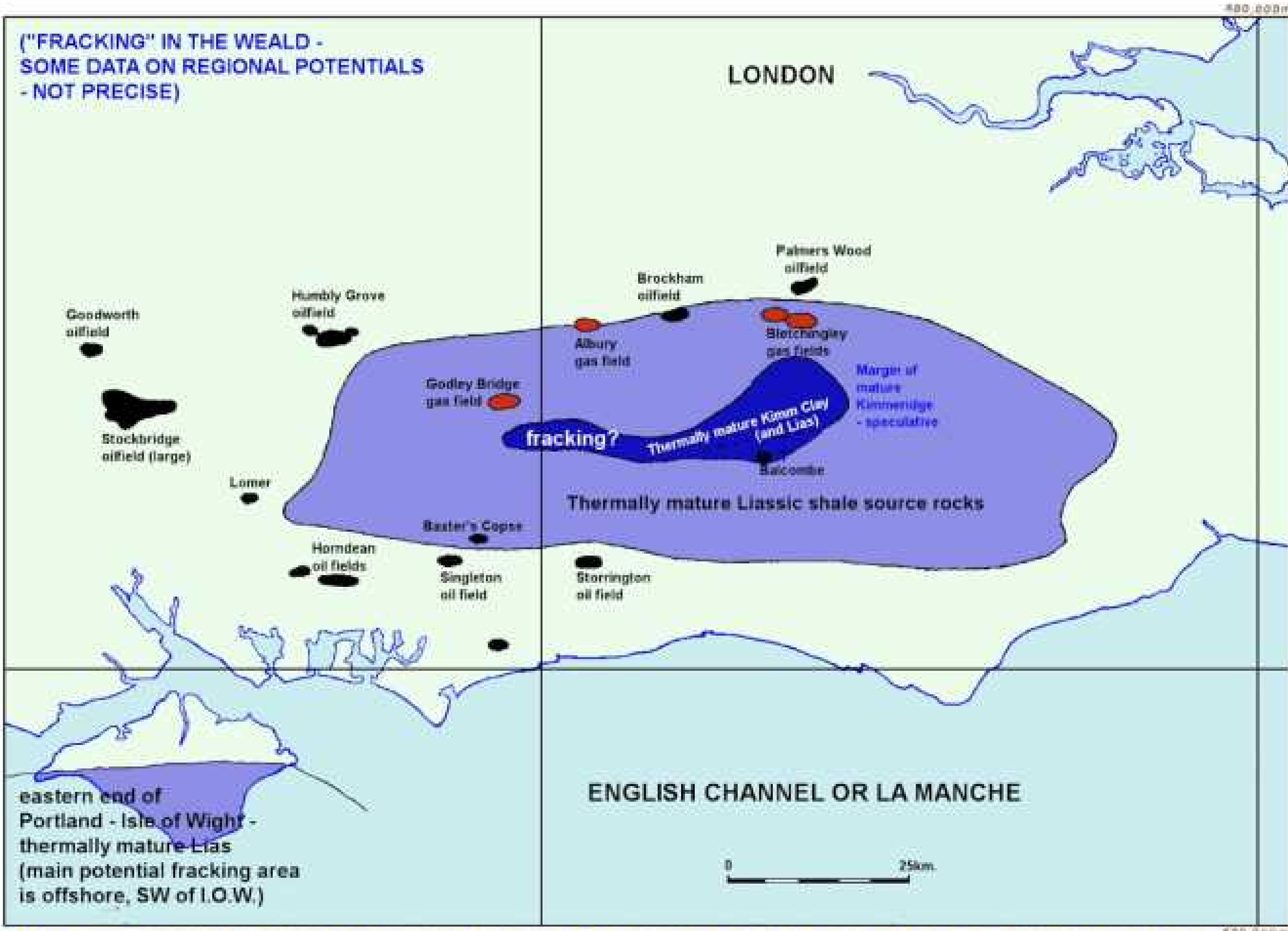
Conventional oil and gas wells in the Weald

Great Oolite is a minor source rock at Wytch Farm in Dorset, supposedly Europe's largest onshore oil field, mostly drilled into permeable sandstone. (In fact, although the wells start on land, most then head laterally out to sea.)

The Weald Basin has a limited history of drilling for oil and gas. It all began by accident in the 1830s when two workmen were killed in a gas explosion in Hawkhurst in Sussex while drilling a water well. Around 250 wells are recorded as having been drilled over the intervening years, most now abandoned. Gas was the early focus, until the 1980s, when high oil prices and new drilling brought some oil discoveries. In the 1990s and 2000s, an average of nine wells were being drilled per year. But many prospectors left the area, finding the wells too problematic and expensive and yields too small. Balcombe 1 well, drilled in the mid-1980s, was one such well, abandoned because oil flow was inadequate. Thirteen 'conventional' sites remain in production, around the fringes of the Weald, drilled into the Great Oolite.

Sulphurous, malodorous

Oil from Kimmeridge formations is 'sour' – smelling of sulphides, rotten eggs, boiled cabbage, hot water bottles… Heated to 200 C it gives off (lethal) hydrogen sulphide, which smells of rotten eggs. It proved too evil-smelling for use on Royal Navy vessels in the First World War, even when fuel was in short supply. The community around Horse Hill reported smells during drilling.



MATURE, JURASSIC SOURCE ROCKS AREAS FOR THE WEALD BASIN, AS POSTULATED BY BUTLER AND PULLAN (1990).
This has been given for the end-Cretaceous, but since there is no Tertiary over the central area it is reasonably applicable for the pr
mature Kimmeridge Clay are speculative, but the general area delineated is likely to be correct. Balcombe, the fracking locality, may
Kimmeridge Clay (but it seems likely). The dark blue area (Kimmeridge mature) may be most favourable for fracking because there
However, areas beyond, with only mature Liassic shales could be subject to fracking in the future. (The map has been redrawn with
Butler and Pullan, 1990, Tertiary Structures and Hydrocarbon Entrapment in he Weald Basin of Southern England, an interesting pa
Ian West, 2013.

Wells in the pipeline

The following sites are either already drilled or proposed to be drilled into reservoirs that are either clearly 'tight'/'unconventional', or suspected to be.

At ***Balcombe, West Sussex*** Cuadrilla drilled the 2013 well vertically for 823 metres and then out for around half a kilometer laterally into the Upper Kimmeridge micrite bed, a 40-metre-thick seam half-and-half clay and micrite. Balcombe's well, it should be underlined, has been drilled into an unconventional formation. A well drilled in the mid-1980s only ten metres away failed to flow at commercial rate, despite being acidised. Cuadrilla announced in early 2014 that they did not after all need to frack the

Balcombe well. They intend to acidise with a solution of 15% hydrochloric acid plus other additives, taking the pressure up to just below fracturing pressure to open and etch the natural fractures – or so the community was told verbally by the drilling team. A flare is planned. Under the terms of their recently revised Petroleum Exploration and Development Licence (PEDL) they have to complete their test flow by 2019, and drill another well in the PEDL by 2021. No second site has yet been announced.

Markwells Wood is in ***West Sussex***, north of Havant (Portsmouth), south of Petersfield, within the South Downs National Park. UKOG have applied to drill a 1km side-arm to the well drilled there in 2011, plus three more production wells and a water injection well (for waste). They want permission to acidise and produce oil at the site for 20 years. The target at Markwells Wood is the Great Oolite limestone, deeper and older than the Kimmeridge micrite. It would appear from previous comments and from the current planning application that the oolite at Markwells Wood is not sufficiently permeable without stimulation – that it is therefore 'unconventional'. The proposed wells would pass through a chalk aquifer that supplies thousands of people with drinking water, including the city of Portsmouth. Portsmouth Water Authority and the Environment Agency have both objected to the application because of risk to drinking water aquifers, as have Chichester and Portsmouth Councils.

Broadford Bridge, West Sussex, is two miles from Billingshurst. The licence for this area was bought by UKOG in the summer of 2016 The Broadford Bridge well already has planning and environmental permissions to drill. They expect to drill into the Kimmeridge Limestone, the same formation as in Balcombe and Horse Hill, and to acidise.

At ***Horse Hill, Surrey***, near Gatwick Airport, has the same geological make-up as Balcombe, but the Kimmeridge micrite there is buried slightly deeper. Developers UKOG recently flow-tested their well in the Upper and Lower Kimmeridge Limestone, plus the Portland Sandstone, with best results from the Upper Kimmeridge. UKOG have now applied to drill and flow-test a further two wells, one to run horizontally into the Kimmeridge Limestone (micrite).

In ***Leith Hill, Surrey***, Europa (with UKOG) have permission, after more than seven years of planning and legal disputes with the local community, to drill 1,400m into the Portland and Corallian Sandstones within the Surrey Hills Area of Outstanding Natural Beauty. Leith Hill is a wooded hill to the south west of Dorking, at 294 metres (965 ft) above sea level the highest point on the Greensand Ridge, and the second highest point in the South East. There will be gas flares. UKOG owns a 20% share. We are waiting for further information on the geology at this site.

Brockham, Surrey is due to be drilled soon. Angus Energy has environmental permits to drill a new horizontal well for oil at Brockham, where a 'conventional' well has been producing from the Portland Sandstone for 20 years. They say that this will help them prolong production from the Portland reservoir while also giving them: 'an opportunity to assess the potential of, and if successful, produce from the Kimmeridge limestones and Top Coralian layer.' This is therefore also a case for hydrochloric acidisation of the limestone, plus (this is conjecture) potentially hydrofluoric stimulation in the sandstone.

At ***Palmer's Wood, Godstone, Surrey,*** Star Energy/IGas have permission for two wells and other infrastructure until 2024. We are waiting for further information on the geology at this site.

At ***King's Farm, Tilburstow Hill Road, South Godstone, Bletchingley, Surrey,*** IGas got permission this year to produce oil and gas for 15 years from two existing wells (one oil, one gas). The nearest house is only 100m away from the gas well! The company has plans but not yet permission to drill an additional four wells. King's Farm is in the Green Belt. We are waiting for further information on the geology at this site.

Wressle, North Lincolnshire, is in the valley of the River Ancholme about 5 miles east of Scunthorpe. Egdon Resources have applied for planning permission to use a 'proppant squeeze', and then to acidise a sandstone and limestone formation with hydrochloric and hydrofluoric acid and produce there for 15 years. Wressle has two Sites of Special Scientific Interest nearby, arable fields immediately adjacent, is rich in watercourses and is surrounded by ancient woodland.

Regulation and monitoring

In California, Florida and Ohio, attempts have been made to regulate acidising on the same basis as fracking, but with little success. In Germany, fracking is currently banned, but acidising to extract tight gas and oil is still permitted. English law and regulation has also concentrated on fracking alone. The English regulators are understaffed, underfunded, facing further cuts, and grappling with Brexit; the Environment Agency is also immersed in floods. Even before recent cuts, there was little actual oversight of oil and gas operations. The regulators admit that they allow the industry to self-monitor. For the oil and gas companies, complying with regulations is expensive, possibly best avoided. And accidents happen. After the 2011 earthquakes at Preese Hall 1 shale gas well near Blackpool, Cuadrilla took six months to inform the government that the well had been damaged ('ovalised') over several hundred feet. This matters, because poor construction or damage to the well is the most likely cause of air, groundwater or formation contamination.

Conclusion

Acidising/acid fracking poses a threat to our environment, health, quality of life and climate. It is one of four processes, including fracking, that could cause oil and gas wells to proliferate in their thousands across our countryside. Yet no one is talking about it. It slips under the radar and avoids the regulation (weak as it is) that now surrounds shale gas. Politicians, NGOs, planners, water companies, regulators and communities need to object to and campaign against acidising as well as fracking for shale gas. And let us not forget underground coal gasification and coal bed methane. But those are subjects for another thesis.

Further easy reading

DIY acidising

Do not try this at home, exciting as it sounds…
http://petrowiki.org/Conducting_the_acidizing_procedure

Very readable paper on acidising carbonate formations, from Schlumberger, Middle East and Asia Reservoir Review
https://www.slb.com/~/media/Files/resources/mearr/num8/51_63.pdf

The American Petroleum Institute on acidising
http://www.api.org/~/media/files/oil-and-natural-gas/hydraulic-fracturing/acidizing-oil-natural-gas-briefing-paper-v2.pdf

Swabbing (sometimes needed after acidising to make a well flow)
http://www.tigergeneral.com/swabbing-well-explaining-process-simple-terms/

Hydrofluoric aid

A Risk Too Great Hydrofluoric Acid in US Refineries, a union publication highlighting accidents, inadequate safety measures and poor preparedness for crisis management http://www.usw.org/workplaces/oil/A-Risk-Too-Great.pdf

Harvard's Guidelines for the Safe Use of Hydrofluoric Acid http://chemistry.harvard.edu/files/chemistry/files/safe_use_of_hf_0.pdf

Blowouts

Letter from a North Sea rig worker: https://peopleandnature.wordpress.com/2013/08/15/gas-blowout-on-totals-elgin-field-letter-from-a-north-sea-oil-worker-to-reclaim-the-power/

German gas cloud: press release April 17th 2014 Frack Free Balcombe Residents Association:
http://www.ndr.de/nachrichten/niedersachsen/lueneburg_heide_unterelbe/Saeureregen-auf-Soehlinger-Erdgasfeld%2cgiftwolke101.htm
http://www.ndr.de/regional/niedersachsen/heide/giftwolke101.htmlhttp://www.radiobremen.de/gesellschaft/themen/regen170.html

Geology

Dr Ian West of Southampton on Weald geology: http://www.southampton.ac.uk/~imw/Petroleum-Geology-Weald-Shale.htm

Industrialisation

Wells 'back to back' across the Weald, UKOG CEO Stephen Sanderson woos investors https://masterinvestor.co.uk/economics/shale-a-new-world-oil-order/

See the video of his speech here: https://www.youtube.com/watch?v=5zBAD-EJHyk

Analysis of potential oil industry across the Weald https://drillordrop.com/2016/04/18/weald-oil-production-could-generate-52bn-over-40-years-but-2400-wells-needed/

Waste water, flowback and produced water

Engineer John Busby on the dilemma of treatment and disposal of water
http://www.after-oil.co.uk/fracking_wastewater.htm

New technology

SqueezeFrac': http://ener-pol.com/products/squeezefrac/

California

Khadeeja **Abdullah's** paper on *Acidizing Oil Wells, a Sister-Technology to Hydraulic Fracturing: Risks, Chemicals, and Regulations*
http://escholarship.org/uc/item/6z9238sj#page-11

Environmental lawyers in California on lack of information on the risks and implications of acidising: http://www.environmenta ldefensecenter.org/wp-content/uploads/2016/08/OffshoreFracki ngEAComments_SBCK_EDC.pdf

Artlicle on lack of oversight of hydrofluoric acid use in California: http://www.takepart.com/article/2013/09/02/acid-california-fracking-acidizing-monterey-shale

Wressle, North Lincolnshire

Summary: https://drillordrop.com/2016/06/30/egdon-applies-for-15-years-of-oil-production-at-lincolnshire-wressle-site/

Planning document, Wrestle
http://www.planning.northlincs.gov.uk/api/Cached/PlanningWeb?ReqType=F&Refno=MIN/2016/810

Markwells Wood, West Sussex

Objection to the planning application by the Environment Agency http://planningpublicaccess.southdowns.gov.uk/online-applications/files/F1050B7B9060001968DA18B7BFE9D5C1/pdf/SDNP_16_04679_CM-ENVIRONMENT_AGENCY-733225.pdf

Objection by Portsmouth Water
http://planningpublicaccess.southdowns.gov.uk/online-applications/files/115F30210D3BFB9D4D37287063AFF507/pdf/SDNP_16_04679_CM-PORTSMOUTH_WATER-724637.pdf