August 2018

Briefing

The acid test: The case for a ban on acid stimulation of oil and gas wells

Acid stimulation is the use of acid to stimulate oil and gas wells to increase production. This briefing explains the terms used, the risks associated with the process and our concerns.

Acid stimulation has been used to improve the production of wells since the 1950s. However, globally there has been a big increase in the use of a range of well stimulation techniques to allow more exploitation of unconventional oil and gas[1]. Drilling more longer horizontal wells has considerably increased the quantity of fluids and acids used[2].

Friends of the Earth's main concerns about acid stimulation are:

- It is being proposed and is potentially already being used in England to increase fossil fuel production. But, to avoid the worst impacts of climate change, we need to reduce fossil fuel use fast. Increasing fossil fuel production is not compatible with the climate change goals the UK has signed up to.
- Regulations are not strong enough to cover the risks associated with acid stimulation. There are significant gaps in knowledge about the chemicals used in the treatments, including overall volumes used, and their toxicity and persistence in the environment, meaning that there are clear risks that residents are right to be concerned about.
- It could involve hundreds of new oil wells, some in our most precious areas of countryside.

For these reasons, we believe the government should immediately put in place a ban on acid well stimulations in England.

Introduction

Government support for the onshore oil and gas industry comes at a time when we know that there are severe climate impacts from extracting more fossil fuels. The vast majority of fossil fuel reserves are unburnable if we want to avoid the worst impacts of climate change. The emissions from just the coal, oil and gas reserves in existing and under-construction projects worldwide will be 942 gigatonnes of carbon dioxide (CO_2), but for a likely chance of keeping below 2 degrees warming, we can emit only 843 gigatonnes of CO_2[3]. The Paris Climate Change Agreement commits nations to keep warming "well below" 2 degrees and "pursue efforts" to keep warming below 1.5 degrees, so to meet Paris targets, clearly we must halt new fossil fuel projects.

The UK has ratified the Paris Agreement and pledged to be a leader on climate action[4]. Existing projects for extraction of fossil fuels take us well over globally agreed goals. There is no space for new projects, whatever the methods used. Acidising is being increasingly proposed and probably already used as a technique to extract hard-to-reach oil deposits in England. It comes with particular risks and concerns that are highlighted in this briefing.

It is hoped that this paper leads to acid stimulation becoming a part of the wider debate about fracking. It highlights information gaps that need addressing as well as concerns about the impacts on our countryside.

What is acid stimulation?

Well stimulation is a broad term used to describe treatments used to restore or enhance the productivity of a well[5]. There are three main types.

Most people have heard of hydraulic fracturing – or fracking, which is one type of stimulation treatment where pressure is used to fracture underground rock. But there are two other treatments which use chemicals injected down wells: acid fracturing (acid fracking) and matrix acidising[6]. Both of these are known as "acid stimulation" or "acidising" and aim to increase the permeability of the rock around the wellbore, to make it easier for oil or gas to flow and be extracted.

However, confusingly, the industry also uses the term acidising to cover a third procedure called an acid wash which clears blockages in or close to wells. The concerns we have are about the "well stimulation" types of acidising: acid fracking and matrix acidising.

Matrix acidising

In matrix stimulation, a solution of diluted acid and other chemicals is injected into the rock to dissolve some of the materials present around the wellbore (this might be the rock itself or damage caused by the drilling) and to create small channels for the oil or gas to flow. This technique is also called 'matrix acidising' or 'acid stimulation' or sometimes simply 'acidising'.

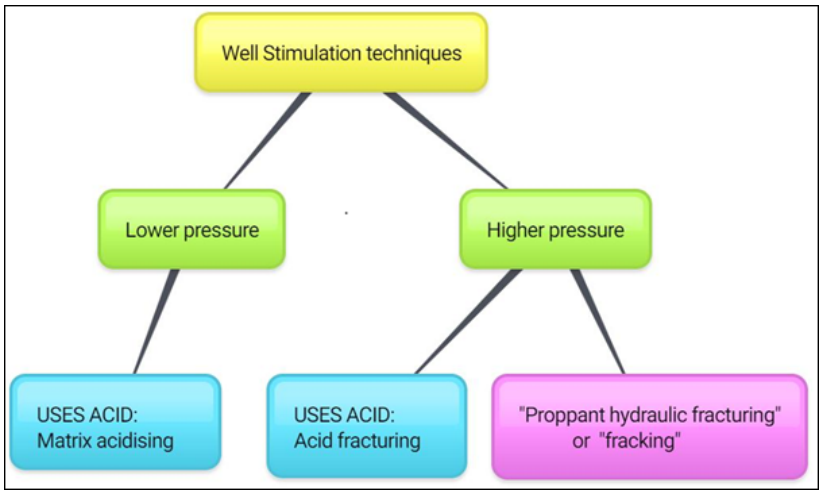
The acid used depends on the nature of the rocks. For formations like limestone which are composed mainly of carbonate minerals, the main acid used is hydrochloric acid (HCl). For formations like sandstone which are composed mainly of silicate minerals, the main acid used is

hydrofluoric acid (HF). However, because the formations are often not just one or the other, a combination of several acids is frequently used, such as 'mud acid', which is a mixture of hydrochloric and hydrofluoric acid[7].

Acid fracturing

The main difference between the two types of acid stimulation is that acid fracturing involves injecting fluid at a pressure high enough to create fractures in the rocks containing the oil or gas. The acid solution dissolves or 'etches' the edges of fractures and channels so that they stay open and allow oil or gas to flow. This technique is used in carbonate and sandstone rock[8].

'Proppant hydraulic fracturing' (also known as high volume hydraulic fracking) is the other form of high-pressure technique, and is what most people know of as fracking. It uses small particles, "proppants", (such as silica sand) mixed with the fracking fluid to keep the fractures open after injection so that the gas or oil can be retrieved. This is used in shale and carbonate rock and some coal beds[9].



What's the problem with acid stimulation treatments?

There are a lot of unknowns about acid stimulation. Whilst we know that many of the chemicals used in the processes can be hazardous, there have been very few studies on the risks and impacts.[10]

There are also concerns that the regulations covering onshore oil and gas exploration aren't strong enough. New regulatory requirements for hydraulic fracturing were introduced in the Infrastructure Act 2015 but the statutory definition of hydraulic fracturing was based on the amount of fluid used in the process rather than the techniques used to extract oil and gas[11].

Acid fracking and matrix acidising use less water than proppant hydraulic fracking[12] so these well stimulation processes are unlikely to be covered by the new regulatory requirements.[13] This is of particular relevance in the Weald Basin where companies are already acidising existing oil wells and applying for new wells[14]. A study based on data from the United States Geological Survey

estimates that 88% of oil wells that were fracked in the US between 2000 and 2010 would not be classified as fracked under UK legislation – based on the fluid volumes thresholds[15].

It is not clear how many wells have received matrix acidising or acid fracturing stimulations in England since this aggregate information is not readily available from the the regulatory bodies[16]. The concern is that even the inadequate regulatory requirements that apply to hydraulic fracturing will not cover acidising operations. For example there is no automatic requirement to carry out baseline monitoring of methane in groundwater nor monitor methane levels in the air. Also there is no legislation banning surface development of acidising sites in protected areas like National Parks[17].

It is also unclear what happens to all the chemicals after they have been used. The acids are supposed to be neutralised when reacting with limestone/carbonate formations but what happens to the other additives? The Environment Agency requires the flowback fluids to be treated and disposed of in approporiate facilities. However "produced water" – the fluid which comes from the underground formations – is allowed to be reinjected. If monitoring of the fate of all the chemicals used in acidising operations is happening, this data appears not to be available publicly[18].

Acid wash – not a well stimulation treatment

Acidising is also a term used for treatments involved in well maintenance and in this context is known as an 'acid wash'. The aim of an acid wash is to remove scale and other deposits forming blockages in the well and pipes. It is not meant to target the surrounding rock[19]. It uses less fluid than for well stimulation, but the composition is broadly the same[20]. It is unclear how regulators and the industry distinguish between an acid wash and matrix acidising. For example when they speak about having used acidising for "decades" they could be referring to acid washing. It is important that there is more clarity when applications are made so that the public and local decision makers know exactly what type of treatment a developer wants to carry out.

What is in the fluid used in acidising?

As with fracking, the fluid injected in both matrix acidising and acid fracking is a mixture of chemicals diluted in water. In hydraulic fracking, the chemicals represent about 0.5% of the total liquid injected down the well. In matrix acidising and acid fracking, the chemicals represent between 6% and 18% of the total liquid[21]. Acid is the main chemical in this mixture. As mentioned above, the acid used depends on the rock formation targeted. In addition to hydrochloric acid and hydrofluoric acid, organic acids such as acetic acid and formic acid can be used.

Several chemical additives with different functions are also added to the mixture. These range from "corrosion inhibitors" to prevent the acids corroding the tubing inside wells, to "biocides" which kill bacteria that can damage wells[22].

Some of these chemicals have the potential to cause direct and indirect impacts on the environment and human health if accidentally released in the air, soil or groundwater at different stages of the process. For example, there can be spills and leaks at the surface or escaping fluids and gases underground[23]. Among the 200 chemicals used for acidising that have been identified in California, studies found that 28 of them are potentially hazardous for human health[24] . Others

could harm aquatic environments and wildlife. For some chemicals, such as hydrofluoric acid, xylene[25] (a highly toxic Volatile Organic Compound), diethylene glycol, and ethyl benzene, an average of between 100 and 1500kg per well is used[26].

Hydrofluoric acid

All acids have corrosive effects and toxic potential but hydrofluoric acid is a particular concern. It can cause severe burns and systemic toxicity (it can have a toxic effect on organs even if it enters the body elsewhere) due to fluoric poisoning. Concentrated hydrofluoric acid burns on as little as 2.5% of the body's surface (the size of the palm of a hand) can cause death[27] . In the past, industrial accidents have exposed whole communities to the toxic effects of hydrofluoric acid[28].

Hydrofluoric acid is frequently used in acid treatments in sandstone. A study on acidising practices in California from 2014 to 2015 revealed that hydrofluoric acid was used in all levels of acidising operations. Acid fracturing used it most frequently and up to 25 tonnes of hydrofluoric acid was used in each acid fracturing treatment[29].

Despite their role in regulating the use of hazardous chemicals used in onshore oil exploration, when asked to clarify where hydrofluoric acid has been used in onshore wells in England, the Environment Agency said they hold no data[30].

How much acid is used?

The volume of fluid needed for well stimulation mostly depends on the length of the formation being treated. According to the industry in the US *"Typical acid volume ranges are between 10 and 500 gallons per foot"*[31]. This corresponds to 0.124 - 6.209 cubic metres of acid per metre of well. So, for a typical horizontal well length of 1,000 metres, this would mean that 124 - 6,209 cubic metres of acid would be used to treat the horizontal part of the well. So this could mean over two Olympic sized swimming pools worth of acid for each treatment[32].

Where will be affected?

And it's not just one well, nor one lot of chemicals. The Weald Basin, in the South East, is a key exploration area for tight oil, which is oil that is not easy to extract[33]. The productivity of tight oil wells can decline quite rapidly so operators are likely to carry out more than one stimulation treatment on a well and usually drill multiple wells into a reservoir[34]. As Stephen Sanderson, CEO, UK Oil & Gas (UKOG) says:

> *"Generally you have to drill a lot of wells close to each other so that you can maintain a certain level of production."*[35]

And UKOG, a key company in the area, reportedly will need hundreds of oil wells to access the reserves under the Weald Basin[36]. Much of this area is designated for its landscape or biodiversity value[37]. We have already seen applications in the South Downs National Park for example.

Lack of data

Although use of acid has been apparently common practice in the oil and gas industry for several decades, it appears that no full overarching health and environmental risk assessment study has been performed. The first toxicological study purely dedicated to acidising was published in the U.S. in 2017[38]. An environmental risk assessment study was mentioned in a conference abstract of 2016[39] but the results appear not to have been published. A strong issue of concern emerging from these preliminary studies is that there are significant data gaps concerning what is known about the acute toxicity of many chemicals used in acidising, their persistence in the environment and their quantity[40].

In California, the state government is studying the risks associated with matrix acidising and acid fracking as well as proppant hydraulic fracking with a view to better regulating all well stimulation processes[41]. The state's Senate Bill 4 provides mechanisms for groundwater and air quality monitoring and public disclosure of all chemicals used[42].

In England the Environment Agency, when asked, had not carried out any studies of its own and has referred to US studies when queried on risk data.[43] It appears that the Environment Agency has not historically given permits for acid well stimulation operations and is unable to provide data on where acidising has taken place[44].

As far as we are aware, there have been no studies to look at the quantities and profiles of chemicals used in acidising operations in England. This means there is a lack of analysis of how much has been used in the past to determine levels of current and future risk. Given the number of applications coming forward this must be addressed.

The government needs to ensure that adequate reporting is carried out by the industry and that relevant cumulative data on chemical use is publicly available.

Fracking and acid stimulation – the case for a ban

Whatever techniques are used, seeking to exploit new oil and gas reserves is incompatible with the need to reduce climate damaging emissions from fossil fuels. Most of the concerns related to fracking are the same in acidising (both matrix acidising and acid fracking)[45]. These include risks of groundwater, air and soil contamination by the chemicals, risks for human health, and risk of earth tremors[46]. There are also the same issues regarding the industrialisation of rural areas with more heavy goods traffic and noise and the large number of wells that might be needed. As with proppant hydraulic fracking there are also concerns about how the waste fluids coming from these sites are being monitored and dealt with.

Additional concerns relate to the high concentration of chemicals (from 6-18% of the total fluid used), the cumulative volumes of fluids and the potential use of highly hazardous hydrofluoric acid.

Why be concerned now?

It is unclear where and on what scale acid stimulation has occurred in England. Even if it has been used for a long time this doesn't mean that it shouldn't be questioned. The context has changed significantly in recent decades with acidising now being used increasingly with horizontal oil and gas drilling globally. There is a need for clear information on the number of wells which have had matrix acidising or acid fracking treatments as well as data on where this is proposed.[47]

The lack of data mentioned above gives cause for concern. Many chemicals used for acidising are hazardous with a poor environmental profile and the impacts of the release of some chemicals are simply unknown.

The oil and gas industry is aware of the environmental risks from acidising. This is shown by discussion of the use of potentially less harmful alternative chemicals for acidising treatments:

> *"Acidizing treatments can help significantly improve the productivity of a well. Safe handling of commonly used corrosive acids, however, is a significant challenge to properly manage during the execution of the treatments. The additives, such as corrosion inhibitors, iron control agents, etc., typically used to mitigate the corrosive impact of acids and other un-wanted reactions during the treatments adds to the complexity of safe handling, while further aggravating the environmental impact of the overall treatment. Higher dosages of additives that are needed at higher treatment temperatures and pressures further compound the challenge. With the industry needs trending to high temperatures & pressures, and stricter health, safety & environmental (HSE) considerations, an alternative stimulation fluid that is suited for all the challenging conditions and be globally applicable with an acceptable environmental profile would be ideal."* [48]
>
> *"There are several concerns with the use of HCl acids: health and safety of the field crew, corrosive nature of the acids for the flow lines and equipment, and environmental effects of the produced HCl."* [49]

Recommendations

In order to address some of the issues highlighted in this briefing Friends of the Earth believes that:

- The government should immediately put in place a ban on acid fracking and matrix acidising well stimulations in England.

We also recommend:

- A full and independent assessment of the health and environmental impacts of acid well stimulations in England is carried out.
- The government should make data publicly available on the number and type of acid stimulations that have taken place in England with estimates of the quantities and types of chemicals that have been used.

- A study is carried out to identify chemicals of concern and how they are being dealt with from all onshore well stimulation operations.
- Surface level development related to acidising of wells should not be allowed in nationally and internationally designated sites.
- A requirement in planning guidance for energy companies to state explicitly if they intend to carry out maintenance acid washing or well stimulation – and the type of treatment planned.

Summary

The key points in this briefing are:

- Well stimulation is a set of techniques used to allow greater exploitation of oil and gas reservoirs.
- One class of these techniques that is well known is “hydraulic fracking” or just “fracking”, but another class is “acid stimulation”
- Acid stimulation is based on the injection into the well of a fluid containing acid and chemical additives. These are at a much higher concentration than used in hydraulic fracking.
- There are two main acid stimulation treatments: matrix acidising (where the fluid is injected below the fracturing pressure of the rock formation) and acid fracturing (where the fluid is injected at pressure above the fracturing pressure of the rock formation).
- Existing oil wells in England may be using acidising techniques but there appears to be no accessible aggregate data on the number of wells and quantities of chemicals being used.
- Many new wells are likely to be drilled using these techniques – some in areas which are designated for their wildlife or landscape value. We have already seen applications in the South Downs National Park for example.
- There is legitimate concern about the use of acid stimulation treatments for oil exploration with the use of long horizontal wells and therefore high volumes of acidising fluid in England.
- The acids and other chemicals pose risks to the environment and local communities,.
- No proper environmental risk assessment study appears to have been performed.
- There are significant data gaps about the toxicity and persistence in the environment of chemicals used in acidising.
- The regulations covering fracking are unlikely to cover acidising well stimulation operations, and this must be addressed.
- In order to avoid catastrophic climate change, new onshore oil and gas extraction projects must be halted whatever processes are used.

[1] *Acidizing - Treatment in Oil and Gas Operators: Briefing paper.* American Petroleum Institute (API) 2014. http://www.api.org/~/media/files/oil-and-natural-gas/hydraulic-fracturing/acidizing-oil-natural-gas-briefing-paper-v2.pdf

[2] Abdullah et al., 2017. Toxicity of acidization fluids used in California oil exploration. Toxicological & Environmental Chemistry, 99(1). http://dx.doi.org/10.1080/02772248.2016.1160285

[3] Oil Change International, 2016, ‘The Sky’s Limit’ http://priceofoil.org/2016/09/22/the-skys-limit-report/

[4] ‘Forward Together’ Conservative Party Manifesto for the 2017 General Election page 42 https://www.conservatives.com/manifesto

[5] Definitions from Schlumberger Oilfield Glossary http://www.glossary.oilfield.slb.com/

[6] *Acidizing - Treatment in Oil and Gas Operators: Briefing paper.* American Petroleum Institute (API) 2014. http://www.api.org/~/media/files/oil-and-natural-gas/hydraulic-fracturing/acidizing-oil-natural-gas-briefing-paper-v2.pdf

[7] *Acidizing - Treatment in Oil and Gas Operators: Briefing paper.* American Petroleum Institute (API) 2014. http://www.api.org/~/media/files/oil-and-natural-gas/hydraulic-fracturing/acidizing-oil-natural-gas-briefing-paper-v2.pdf

[8] *Acidizing - Treatment in Oil and Gas Operators: Briefing paper.* American Petroleum Institute (API) 2014. http://www.api.org/~/media/files/oil-and-natural-gas/hydraulic-fracturing/acidizing-oil-natural-gas-briefing-paper-v2.pdf

[9] Zoveidavianpoor, M. et al., 2013. Well stimulation in carbonate reservoirs: the needs and superiority of hydraulic fracturing. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 35(1), 92-98. http://dx.doi.org/10.1080/15567036.2011.644389

[10] The few studies there are have been carried out mainly in California and they highlight the lack of data concerning the, quantities and profiles of the chemicals being used in both acidising treatments and hydraulic fracking. See WT Stringfellow et al, Identifying chemicals of concern in hydraulic fracturing fluids used for oil production, Environmental Pollution 220 (2017) 413-420

[11] Section 4B of the Petroleum Act 1998 as amended by the Infrastructure Act 2015

"Associated hydraulic fracturing" means hydraulic fracturing of shale or strata encased in shale which—
(a)is carried out in connection with the use of the relevant well to search or bore for or get petroleum, and
(b)involves, or is expected to involve, the injection of—
(i)more than 1,000 cubic metres of fluid at each stage, or expected stage, of the hydraulic fracturing, or
(ii)more than 10,000 cubic metres of fluid in total. https://www.legislation.gov.uk/ukpga/2015/7/section/50

[12] Average water used in acidising in California is 60,000 – 700,000 kg per treatment. Whereas hydraulic fracking in other states uses an average 421million kg per well. Abdullah et al., 2017. Toxicity of acidization fluids used in California oil exploration. Toxicological & Environmental Chemistry, 99(1), 78-94. http://dx.doi.org/10.1080/02772248.2016.1160285

[13] In a letter from BEIS it is clear that the liquid volumes threshold used to define when fracking regulations apply were set to exclude acidising well stimulation treatments: *"The reason for setting any threshold here is to ensure that the well stimulation techniques used for decades in conventional onshore oil and gas operations, which fracture using lower volumes of fluid, are not inadvertently impacted."* Extract from BEIS letter to Ms L Inglis, 18 October 2017

[14] Sites where acidising is believed to have either been used or is intended include: Balcombe, Lidsey and Broadford Bridge in West Sussex, Horndean in Hampshire and Leith Hill, Horse Hill and Brockham in Surrey.

[15] S Gilfillan and S Haszeldine, 2016, What's in a Name: The Risks of Redefining Fracking, http://energyandcarbon.com/whats-in-a-name-the-risks-of-re-defining-fracking/

[16] There appears to be no central resource setting out the number of wells which have been acid fracked or matrix acidized in England. A reply from the Environment Agency to a resident in January 2017 states that "There have not been any acid well stimulations permitted to date by the EA." This was in response to the question: "Please list any studies conducted by the EA with regard to the composition of fluids returning to the surface as return flows and produced water with regard to well stimulation fluids using acids." Letter available on request. Friends of the Earth asked the Environment Agency the following questions on 26 October 2017 and we are still awaiting a reply.. **"**Do you keep a register of well sites in England which have been stimulated using matrix acidising, acid fracturing and hydraulic fracking? Will you consider collating a publicly available database of sites which are using well stimulation techniques?"

[17] Unless the volume of fluid used meets the statutory definition of hydraulic fracturing.

[18] A paper published by the Environment Agency makes no mention of monitoring of the content of waste arisings from acidising operations. Environment Agency, Use of acid at oil and gas exploration and production sites, January 2018 https://consult.environment-agency.gov.uk/onshore-oil-and-gas/onshore-oil-and-gas-regulation-information-page/supporting_documents/Acidisation%20FAQs%20January%202018.pdf

[19] See Shlumberger Oilfield Glossary http://www.glossary.oilfield.slb.com/Terms/a/acid_wash.aspx

[20] Abdullah et al., 2017. Toxicity of acidization fluids used in California oil exploration. Toxicological & Environmental Chemistry, 99(1), 78-94. http://dx.doi.org/10.1080/02772248.2016.1160285

[21] Abdullah et al., 2017. Toxicity of acidization fluids used in California oil exploration. Toxicological & Environmental Chemistry, 99(1), 78-94. http://dx.doi.org/10.1080/02772248.2016.1160285

[22] The most commonly used chemical additives in acid jobs in the US (see Abdullah et al) are:

Breakers: reduce the viscosity of a fluid
Cross-linkers: maintain fluid viscosity as temperature increases
Clay control agents prevent clay from swelling or shifting
Iron control agents; prevent the precipitation of metal oxides
Scale control agents; prevent scale deposits in a pipe
Corrosion inhibitors: slow down the corrosion rate of a material
Biocides: to kill bacteria that can corrode well casings

[23] See for example http://www.bbc.co.uk/news/science-environment-39032748

[24] See Abdullah and Stringfellow studies. The chemicals used include:
Carcinogens: substances which cause cancer
Neurotoxins: substances which are poisonous or destructive to nerve tissue
Mutagens: substances which cause changes to genetic material
Reproductive toxins: substances which alter sexual function and fertility
Developmental taxins: substances which affect body regulation, growth, development and behaviour
Endocrine disruptors: substances which interfere with the hormone system

[25] Zoveidavianpoor, M. et al., 2012. Health, safety, and environmental challenges of xylene in upstream petroleum industry. Energy & Environment, 23(8), 1339-1352. http://dx.doi.org/10.1260/0958-305X.23.8.1339

[26] Abdullah et al., 2017. Toxicity of acidization fluids used in California oil exploration. Toxicological & Environmental Chemistry, 99(1), 78-94. http://dx.doi.org/10.1080/02772248.2016.1160285

[27] Bertolini, J.C., 1992. Hydrofluoric acid: a review of toxicity. The Journal of emergency medicine, 10(2), pp.163-168. http://dx.doi.org/10.1016/0736-4679(92)90211-B

[28] Wing, J.S. et al., 1991. Acute health effects in a community after a release of hydrofluoric acid. Archives of Environmental Health: An International Journal, 46(3), pp.155-160. http://dx.doi.org/10.1080/00039896.1991.9937443

[29] Hydrofluouric acid was used in 234 out of 474 acid wash treatments, 41 out of 90 matrix acidising treatments and 9 out of 10 acid fracturing treatments.in California between April 2013 and August 2015. Abdullah et al., 2017. Toxicity of acidization fluids used in California oil exploration. Toxicological & Environmental Chemistry, 99(1), 78-94. http://dx.doi.org/10.1080/02772248.2016.1160285

[30] See the response of the Environment Agency, 14 July 2016, to a Freedom of Information request 30 June 2016, https://www.whatdotheyknow.com/request/use_of_hydrofluoric_acid_at_onsh

[31] *Acidizing - Treatment in Oil and Gas Operators: Briefing paper.* American Petroleum Institute (API) 2014. http://www.api.org/~/media/files/oil-and-natural-gas/hydraulic-fracturing/acidizing-oil-natural-gas-briefing-paper-v2.pdf

[32] An Olympic swimming pool typically holds 2,500 cubic metres of water

[33] Weald Basin Jurassic Shale Study, British Geological Society, May 2014
https://www.gov.uk/government/publications/bgs-weald-basin-jurassic-shale-reports

[34] The Kimmeridge formation under the Weald Basin has been likened to the Bakken shale area in North Dakota. Steep declines in well production are a feature of development there. See Benefitting from Unconventional Oil, Headwaters Economics, April 2012 https://web.stanford.edu/group/ruralwest/cgi-bin/projects/headwaters/Bakken-Energy-Report-Headwaters-BLC-120424.pdf

[35] Tip TV interview with Stephen Sanderson, “Game Changer for UKOG, the Weald Basin and the UK Oil and Gas Industry https://vimeo.com/156250494 UKOG is a company with extensive interests in oil sites across southern England.

[36] Gatwick Oil could add billions to UK Economy. http://www.bbc.co.uk/news/business-36069751

[37] An investigation found that 47% of the area licenced for oil exploration above the Kimmeridge formation in the Weald is made up of protected landscapes and habitats. https://unearthed.greenpeace.org/2018/03/15/home-counties-shale-oil-acid-drilling-balcombe/

[38] Abdullah et al., 2017. Toxicity of acidization fluids used in California oil exploration. Toxicological & Environmental Chemistry, 99(1), 78-94. http://dx.doi.org/10.1080/02772248.2016.1160285

[39] Sutra, E. et al., 2016. Chemical stimulation in unconventional hydrocarbons extraction in the USA: a preliminary environmental risk assessment. In EGU General Assembly Conference Abstracts, Vol. 18, p. 12081.

[40] A study like this for England would start to remedy some of the data gaps. Stringfellow, W. T. et al., 2017. Identifying chemicals of concern in hydraulic fracturing fluids used for oil production. Environmental Pollution, 220, 413-420.http://dx.doi.org/10.1016/j.envpol.2016.09.082

[41] Long, J. et al., 2015. An Independent Scientific Assessment of Well Stimulation in California Volume II - Potential Environmental Impacts of Hydraulic Fracturing and Acid Stimulations. CCST report, 761p. http://ccst.us/projects/hydraulic_fracturing_public/SB4.php

[42] California Senate Bill No. 4, Chapter 313: California Statutes and Regulations for the Division of Oil, Gas, & Geothermal Resources, State of California, Jan 2017 ftp://ftp.consrv.ca.gov/pub/oil/laws/PRC10.pdf

[43] See Environment Agency reply to question 25 from Mrs E Mott, January 2017, where she asks about studies relating to pollutants from acidisation. The answer refers back to previous questions where th Agency refers to two US reports implying no studies have been carried out by the Environment Agency itself. Full reply available on request.

[44] Reply from Enironment Agency to Mrs E Mott January 2017, reply to question 27 “There have not been any acid well stimulations permitted to date by the EA”. In the same letter they also state however: *“Much of the activity proposed is not new and has been commonly used in conventional onshore oil and gas exploration for decades.*

[45] Shonkoff et all, 2015, Scientific Assessment of Hydraulic Fracturing in California: Ch 6, Potential impacts of well stimulation on human health in California, CCST http://ccst.us/projects/hydraulic_fracturing_public/SB4.php

[46] Induced earthquakes are mainly thought (in US studies) to be as a result of reinjection of flowback “water”. And interestingly this can be from conventional fossil fuel extraction too. See https://earthquake.usgs.gov/research/induced/myths.php

[47] See for example Gallegos, T.J., and Varela, B.A., 2015, Trends in hydraulic fracturing distributions and treatment fluids, additives, proppants, and water volumes applied to wells drilled in the United States from 1947 through 2010—Data analysis and comparison to the literature: U.S. Geological Survey Scientific Investigations Report 2014–5131, 15 p., *http://dx.doi.org/10.3133/sir20145131*.

[48] Braun, W., et al., 2012. Improved health, safety and environmental profile of a new field proven stimulation fluid. In SPE Russian Oil and Gas Exploration and Production Technical Conference and Exhibition. Society of Petroleum Engineers. http://dx.doi.org/10.2118/157467-MS

[49] Markey, F., 2014. Examining Innovative Techniques For Matrix Acidizing In Tight Carbonate Formations To Minimize Damage To Equipment And Environment. Unconventional Resources Technology Conference (URTEC). http://dx.doi.org/10.15530/urtec-2014-1935101