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McAleenan, C., Weatherup, R., Bogle, G., & McAleenan, P. (2016). Shale gas extraction – the case for a multi-disciplinary study. *Proceedings of the ICE - Energy*, *168*(1), 41-46. Advance online publication. https://doi.org/10.1680/ener.14.00022

Published in:
Proceedings of the ICE - Energy

Publication Status:
Published online: 06/03/2016

DOI:
10.1680/ener.14.00022

Document Version
Publisher's PDF, also known as Version of record

Energy
Volume 168 Issue EN1

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ice | proceedings

Proceedings of the Institution of Civil Engineers
Energy 168 February 2015 Issue EN1
Pages 41–46 http://dx.doi.org/10.1680/ener.14.00022
Paper 1400022
Received 01/07/2014 Accepted 13/01/2015
Published online 06/03/2015
Keywords: fossil fuels/health & safety/infrastructure planning

Shale gas extraction – the case for a multi-disciplinary study

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Shale gas extraction (SGE) and, more precisely, hydraulic fracturing, also known as fracking, has a propensity to court controversy wherever it is proposed. Many processes within SGE are essentially civil engineering processes and while numerous studies into the efficacy of SGE exist, answers to ethical and societal questions relating to safety, health and environmental sustainability remain unanswered. Recently, the UK Department of Energy and Climate Change announced its intention to support studies that encourage the development of innovative technologies for safe and responsible exploitation of the UK's shale gas resources. This paper explores the current state of knowledge regarding safety, health and wellbeing in the SGE industry, and presents the case for a detailed multi-disciplinary value-engineering study to develop pre-drill assessments and to provide ongoing monitoring tools that will assure public authorities, market operators and citizens that best-practice environmental, safety and sustainability approaches are available and feasible.

1. Shale gas and the hydraulic fracturing process

The oil and gas extraction and production industry has a long history, stretching back over a century. Conventional oil and gas extraction and production is so termed because it involves drilling down to where the deposits are situated; once penetrated, the gas or the oil flows up the well to the surface. Gas and oil trapped in the impermeable shale deposits, although essentially having the same product, require a more complex process to release them. Hydraulic fracturing (HF) of the shale to extract oil and gas is one of the industry's many processes. HF, also known as 'fracking', refers to the process of fracturing the layers of oil- and gas-bearing shale hydraulically, using liquids at high pressure, to allow their trapped fluids to be released into specially constructed collection wells. Developed around 60 years ago in North America (King, 2012), and finding a fresh surge in recent times, HF for shale gas extraction (SGE) is now also practised in Europe and Asia.

When exploration establishes the presence of commercially exploitable SGE, it follows through a number of phases (DECC, 2013).

1.1 Drilling and completions

A well is drilled vertically down to the shale play (at depths upwards of 1–2 miles). The well borehole is continued horizontally for up to 2 miles into the shale. Several horizontal boreholes can be drilled from a single well pad. The well borehole is lined with a series of concentric metal casings that are cement sealed to avoid contamination of the surrounding ground and groundwater.

1.2 Hydraulic fracturing

Gas flow lines are created in the shale though a process of HF, where a fluid mix (sand, water and a 1–2% proportion of chemicals) is injected at high pressure down the well creating a fracture in the shale. The sand is used to prop the fractures open to facilitate gas flow.

1.3 Production

The released gas flows up the well to the surface for processing and distribution.

Drilling and completions, and the HF process, ordinarily last for a few months. This is effectively the civil engineering/construction aspect of gas recovery. The production process can then last for several years, depending on the quantity and quality of the reserves. Typically, well pads comprise 6–8 wells but can contain up to 16 (Mohajan, 2012) and possibly as many as 24 wells (Kibble *et al.*, 2013) covering an area between 1·5 and 3 ha (1 ha = 10 000 m^2). Composite Energy (now Dart Energy) estimates that well pad spacing in the UK will be between 1 and 1·5 well pads per km^2 (cited by Wood *et al.* (2011)). In the USA, Marcellus basin spacing is 3·5 per km^2 (Mohajan, 2012). Multi-well pads contain storage facilities and pits for flow-back fluids (estimated between 15 and 80% of fluid injected into the well (Mohajan, 2012)), equipment for drilling and processing, and flow-back recycling facilities; 80% of flow-back is capable of being recycled using current technologies (Mohajan, 2012).

At each stage of the fracturing process, each well requires between 1100 m^3 and 2200 m^3 of water, amounting to 9000–29 000 m^3 in total, of which 180–580 m^3 is the chemical additives necessary for different aspects of the process. A six-well pad will require between 54 000 m^3 and 174 000 m^3 of water and 1000–35 000 m^3 of chemical additives (Wood *et al.*, 2011). A 3 m deep storage pit with a volume capacity of 2900 m^3 has a surface area of 1000 m^2 and in a six-well pad 7900–138 000 m^2 will be required for a single HF operation, with 160–2700 m^3 being fracking chemicals and contaminants (Mohajan, 2012). The wide difference between the low and high is accounted for by the difference in depths and horizontal distances at different extraction sites. There are approximately 600 different chemicals used in the HF and extraction process (Kibble *et al.*, 2013) of which almost 30 are known to cause or be contributors to cancer (Colburn *et al.*, 2011). Flow-back fluids are themselves contaminated by salts absorbed from the rocks they have passed through; an estimated 20% of this is not recyclable (Mohajan, 2012). HF requires substantial quantities of high-specification sand with approximately 1800 tons per well being needed (Kibble *et al.*, 2013). In the USA, the industry demand for 'frack sand' increased from 10 million tons in 2009 to 33 million tons in 2013 (King, 2014). The high specification means that the sand has to be obtained from geological deposits of high-purity silica – that is, sand that is up to 99% silica. In a study carried out by the National Institute for Occupational Safety and Health (NIOSH, 2012), seven primary sources of airborne silica exposure were identified during HF operations, of which 47% were greater than the Operational Safety and Health Administration's permissible exposure limit (PEL) and 9% were more than ten times greater. The USA's PEL and the UK's workplace exposure unit (WEL) are both at 0·1 mg/m^3 for pure quartz silica, a figure that is substantially below the exposure level for amorphous silica at 6 mg/m^3.

New York State (cited by Wood *et al.* (2011)) estimates between 4300 and 6600 truck visits per well pad, of which 90% are associated with the HF operation itself. The calculation of the road mileage covered is complicated by a range of factors that include the distance from sand quarries, chemical production facilities, and drilling equipment manufacturers and distributors. The UK Department of Energy and Climate Change (DECC) commissioned a strategic environment assessment (SEA) on proposals for further onshore oil and gas licences in Great Britain (DECC, 2013). The assessment, also cited by Kibble *et al.* (2013), made a number of assumptions based on high and low activity scenarios

- between 50 and 150 licenses issued
- between 30 and 120 well pads constructed with
  - six to 24 wells per pad and
  - covering 3 ha
- peak number of wells drilled per year, 360
- maximum number of wells drilled, 2880 (producing 85·6 million m^3)
- 20 years lifetime per well.

Table 1 estimates the volume of materials required, and truck journeys and land used for SGE in the UK, based on the SEA assumptions.

2. SGE – the issues

The extraction of natural gas from shale formations is one of the fastest growing trends in US on-shore domestic oil and gas production (Ground Water Protection Council, cited by Jackson *et al.* (2011)). USEIA (2011) estimates that there are 750 trillion cubic feet (tcf) of technically recoverable shale gas resources in three regions of USA: the North East, the Gulf Coast and the South West. These current figures (2011) greatly expand previous estimates where it was reported (Moss, 2008) that 31 tcf might be recoverable from the Marcellus formation in the North East region of USA, compared with INTEK's estimate or 410 tcf (cited by USEIA (2011)). A recent study conducted for the Institute of Directors (Taylor, 2013) suggests that the UK could have as much as 309 tcf of shale gas in place (resources), which at a conservative estimate would be technically and economically recoverable at a rate of 10%, giving the UK potentially 30·9 tcf of usable shale gas (reserves). These figures are greatly increased in a British Geological Survey (BGS) study (Andrews, 2013) where in the Bowland Shale play (North of England) reserves estimates are set at 1300 tcf. An EU-wide study (Mathis *et al.*, 2014) estimates that member states in totality have recoverable shale gas in the order of 805 tcf. The Institution of Civil Engineers (ICE) holds the view that while there are still many uncertainties over the role that shale gas can play (in energy security), '…shale gas represents a promising additional source of energy that should be further investigated within an enhanced regulatory framework' (ICE, 2012).

A BGS report (BGS, 2011) for UK's DECC focused primarily on potential seismological activity, recommending stricter controls and procedures for developers extracting shale gas in the UK; however, there are other equally pressing environmental, public safety and health matters that need to be addressed. The recent growth in the practice of SGE has brought environmental, public safety and health concerns to the fore. As the potential for SGE expands across Europe, the European Commission and each member state (EC, 2014a) need assurances

- of the environmental integrity of extraction of unconventional hydrocarbons, such as shale gas

	30 well pads		120 well pads	
	Min. 180 wells	Max. 720 wells	Min. 720 wells	Max. 2880 wells
	Well pad area requirements: m^2			
3 ha per six wells	22·5–90	90–360	90–360	360–1440
30 000 m^2per six wells	0·675–2·7 million	2·7–10·8 million	2·7–10·8 million	10·8–43·2 million
	Water and chemical requirements: m^3/well			
Water 9000–29 000	1·62–5·22 million	6·48–20·88 million	6·48–20·88 million	25·92–83·52 million
Chemicals 180–580	32 400–104 400	129 600–417 600	129 600–417 600	518 400–1 670 400
	Frac fluid storage capacity per six wells (surface area): m^2			
7900–138 000 m^2	237 000–4 140 000	948 000–16 560 000	948 000–16 560 000	3·792–66·24 million
	Sand; 1800 tons per well			
	324 000	1 296 000	1 296 000	5 184 000
	Truck visits			
4300–6600 per six wells	129 000–198 000	516 000–792 000	516 000–792 000	2·352–3·168 million

Table 1. Estimates of materials, storage and transport requirements for HF operations in Great Britain based on DECC SEA assumptions and empirical data obtained from USA operations as presented in the Mohajan (2012) study

- that risks that may arise from individual projects and cumulative developments are managed adequately in member states wishing to explore or exploit shale gas resources.

The Commission responded to member states' calls for action by adopting recommendation 2014/70/EU (EC, 2014a) in an effort to contribute to bringing clarity and predictability to public authorities, market operators and citizens. The Horizon 2020 Energy Work Programme (EC, 2014b) states that '…in the delivery of secure, clean and efficient energy low carbon technologies it is important to develop and bring to market affordable, cost-effective and resource-efficient technological solutions in a sustainable way…'. As such it appears that in an EU context some of the most immediate SGE issues that need to be addressed are the associated environmental concerns, in particular through

- developing a better understanding of the fracturing process and its environmental effects
- advancing the treatment and recycling of flow-back and produced water
- mitigation of induced seismicity and emissions to air.

While the EU has an overarching role to play in regulation, the actual decisions are made in planning terms at member state level. The onus therefore is on each public authority to put a framework in place that will ensure that, should SGE proceed, it is properly regulated to ensure a safe and sustainable future. The framework, designed to minimise the environmental footprint, based on a sound knowledge base and scientific recommendations, will need to address short-term environmental risks, such as water contamination, induced seismicity and air pollution, and the longer-term risks, including wastewater disposal, depletion-induced subsidence or injection-based heave. Given the EU Sustainable Development Strategy's strong emphasis on social and territorial cohesion and environmental protection (EU, 2006), and the EU directive on protection of workers' safety and health (EC, 1989), it would seem logical that all are deemed integral to assessment of the environmental impacts of SGE.

In the UK, the Health and Safety Executive has regulatory responsibility for well design and construction and, among other things, it requires independent verification of the well design and a detailed examination of its integrity during construction and operation. Additional scrutiny is afforded through the planning process, where the Environment Agency has responsibility to consider both the strategic and the environmental impact of any proposed SGE operation.

3. SGE – the challenge

McAleenan *et al.* (2013), citing Lechtenbohmer *et al.* (2011), who in a report to the European Parliament advocated the need for a reassessment of the full impacts of SGE, concluded that there was a wide range of conceivable accident risks such as 'blow out with frack-water spills, leakages from wastewater or from fracture fluid ponds or pipes, groundwater contamination due to improper handling or unprofessional cementing of the well casing'. Lechtenbohmer *et al.* (2011) argue that the realisation of these could well be due to inconvenient handling, increasing economic pressures resulting in a speeding up of the process, which has the potential to decrease due diligence in hazards control with a consequent increase in the frequency of accidents. However, they believe that these risks can be reduced and probably avoided with adequate technical directives, cautious handling practice and supervision by public authorities. Ewen *et al.* (2012), in contemplating the future for SGE, concluded that there was no need for an outright ban on the practice of HF, acknowledging that until now several unknowns exist with regard to the environmental and health impact of the process. They suggested proceeding with caution, not whole scale, indicating that 'a defined state of the art; a legal framework that addresses the new risk dimension entailed by hydrofracking [sic]; and additional scientific knowledge' is necessary if the process is to proceed. McAleenan *et al.* (2013) advise that an element of realism exists, which recognises that gas extraction is going to be part of the immediate future but that it should not be carried out in isolation from other human activities and needs in respect of the environment. Rather, it must be fully integrated within national biodiversity and social protection measures. Where harm, real and alleged, has occurred, independent, objective assessments are required that will determine the nature of the harm, its causes and what will be required to remedy the situation and prevent reoccurrences. Should environmental impact assessment processes and continual sustainable monitoring regimes become an accepted industry standard guidance within EU, and the member states implement the guidance within their regulatory framework, that will go a long way in ensuring that it gains social acceptance. Consequently, the industry can move forward in a socially responsible manner, providing that concerns of the citizens regarding their health, safety and wellbeing can be allayed.

4. SGE – safety, health and wellbeing – what we know

There are many hazards in the SGE industry of which the degree of exposure and the extent of appropriate controls still have to be tackled. The global growth of the SGE industry has raised safety, health and environmental concerns and yet, while much has been written and spoken about the scientific and technical aspects of SGE, issues such as workplace safety and health still lack the critical examination that is required if the discussion, and ultimately any final choices, are to be appropriately informed. As the SGE debate progresses, the decision as to whether it should continue, or even expand, research into the ability to control worker safety and health by engineering controls and through managerial procedures has to take a higher priority in order that final choices are appropriately informed. Cleary (2012) referred to the many unknowns to date, focusing specifically on citizens' health and wellbeing and pointing to the fact that often public health agencies are late getting involved with initiatives regarding regulating industries such as SGE. Consequently, medical health, public health and environmental health tend to either have a 'back seat' or 'miss the bus altogether'. Kibble *et al.* (2013), in a report for Public Health England, noted that the findings relating to health impacts within the SGE process were inconclusive and likely to vary depending on the scale of operations. The recommendations of the report include the need for more public health studies and monitoring of any future 'roll-out' of SGE across the UK. In USA reviews of occupational safety and health hazards associated with HF, health, and in particular worker exposure to respirable crystalline silica, was the dominant hazard discussed (NIOSH, 2012). Not being fully aware of the extent of, location of and rate of development makes it more difficult to predict the size of the challenge facing the community. How many increased traffic movements are necessary to service the HF process and will this naturally lead to increased traffic collisions? What volume of water, sand and associated chemicals are needed, and how does this impact on environmental and citizens' health?

Maybe the question to be raised is what is known about public health, workers' safety and health impacts stemming from conventional oil and gas development and how does that compare with the unconventional SGE. The research methods employed to date have been largely exploratory, focusing on current literature and interviews with key players in SGE industry and associated fields. More is needed. The work going forward has to engage with regulators, affected communities and SGE operating companies to define adequately the nature of safety-, health- and environment-related hazards in SGE, from each of their perspectives. The outcome will help lead to the identification of solutions that could be developed to offer an enhanced/improved sustainable performance within the industry.

5. SGE – the proposed study

Presently, there are still no definitive answers to the societal questions relating to safety, health, wellbeing or environmental sustainability. Perhaps much of that can be blamed on a high degree of confusion/scepticism promulgated within popular media and may even be on information overload. What is it that makes a person hold firm to their belief in the face of what is overwhelmingly conclusive and scientifically proven information? Is it lack of trust? Fear? Or is there a crowd mentality leading to a universality of behaviour? As the debate to determine the future for SGE continues, the adoption of a multi-disciplinary approach is needed, involving science and engineering, health and psychology, and value and safety engineering, exploring how functional aspects combine in the delivery of sustainable development through knowledge, skills and professional expertise. Individually, it is possible that SGE construction sites present no greater a series of hazards than those presented with any other construction project. However, given the scale of the operations, with the potential for extensive numbers of SGE sites being developed across Europe in the coming years, the issue could come down to repeated and frequent exposure to some hazards, together with the considerable associated volumes of material and quantities of truck movements (Table 1), which present specific concerns for safety and/or health. As with the community health issues (Cleary, 2012; Kibble *et al.*, 2013) workers exposed on a long-term basis to hazards such as respirable crystalline silica (NIOSH, 2012) and extensive transportation/traffic hazards, there remain a lot of unanswered questions. Is there a viable supply chain in place with all the necessary management controls? To what size is the industry likely to expand? While the concerns will revolve around safe design, construction, operation and, ultimately, demolition, the exact nature of the issues must first be determined if controls are to be effective at each stage of the process.

The proposed study sets out with no preconceptions about SGE; rather, it sets out with the aim of developing the tools that will allow objective decisions to be made by all concerned. This necessarily will involve all of the key stakeholders in the study and in the dissemination of deliverables. The study proposes concentrating on further developing the scientific knowledge base, focusing on both the geo-environmental and the societal aspects of the SGE industry from the conception/exploration stage, through exploitation to final completion and exit. The exit strategy has to include well abandonment in a safe and sustainable manner, taking cognisance of the potential for future redrilling, should future technologies render further extraction financially and technologically viable.

Logically, then, there is a need to study the safety, health and wellbeing of SGE operatives to determine whether they are exposed to new or unique hazards, in order to be in a position to recommend best practice control measures, based on the intervention practices of industry's best performers. The follow-up work should establish the efficacy of eliminating or mitigating safety and health hazards, using established and emerging safety management and safe design practices. Equally, complementary work is required to determine impacts on citizens' health associated with SGE (Cleary, 2012) with a holistic approach focused on the inter-related conditions and factors that influence the health of a population. The determinants of citizens' health include, among others, social, economic, biological and physical factors, and therefore the study needs to scrutinise socio-economic and psycho-social impacts, examining existing health impact models to establish what critical factors have to be addressed.

6. SGE – the study ambition

Successful conclusion of a project of this nature will deliver the knowledge base and scientific recommendations that will allow public authorities, market operators and citizens to make objective decisions regarding minimising the SGE environmental footprint. Building on the knowledge and experiences in the USA and Canada, the inter-related best practices documents should present an opportunity for the development of harmonised standards across all EU member states. The project also has the potential to influence EU policy in the SGE sector, tying in with the European Commission's recommendation (EC, 2014a), which calls for more clarity and predictability. While the EU has an overarching role to play in regulation, the actual decisions are made in planning terms at the member state level. The Commission has invited member states to follow minimum principles when applying or adapting their legislation applicable to hydrocarbons exploration or production using high-volume HF. The onus is on public authorities to put the framework in place, which will ensure that, if SGE is to proceed, it is properly regulated to ensure a safe and sustainable future.

Ultimately, there is a need to develop and deliver credible, unambiguous and impartial information on all facets of SGE. Should the environmental impact assessment processes and continual sustainable monitoring regime become accepted as industry standard guidance, and should member states implement the guidance within their regulatory framework, it would go a long way towards ensuring social acceptability. It will enable the SGE industry to move forward in an ethical and socially responsible way, assuming the citizens' concerns can be assuaged, greatly improving the likelihood of realising energy security across Europe.

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