Public and Workplace Safety and Health in Hydraulic Fracturing

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Abstract

Fracking, a universally recognised term, which refers to hydraulic fracturing of gas bearing rock layers allowing their gas to be released into specially constructed collection wells. Practiced in North America, Europe and Asia the growth of this industry brings environmental and public health concerns to the fore. In April 2012 the UK's Department for Energy and Climate Change released an independent report, focused solely on potential seismological activity, which recommends stricter controls and procedures for developers extracting shale gas in the UK. Also in 2012 a North Carolina conference convened with the following objective; "to facilitate informed discussion to ensure that science-based policy decisions are made on energy development that will best serve the citizens …". A symposium on emerging hazards, at the EU OSH Strategy conference 2012, discussed how existing hazards were reemerging in new industries, particularly the fracking industry. While much has been written and spoken about the scientific and technical aspects of fracking, issues such as public and workplace safety and health need to be thoroughly addressed if the debate and ultimately final choices are to be appropriately informed.

The researchers preliminary scoping found concerns about; increased salinity of water supply adjacent to fracking sites, respirable crystalline silica dust in sand extraction sites, air and water quality, toxicity of drilling fluids and hazardous wastes. In this paper the authors adopt a multi-disciplinary approach involving value engineering, sustainability and ethics; exploring how functional aspects of engineering's societal responsibility; delivering sustainable development through knowledge, skills and professional expertise, are being addressed. In particular it;

- Provides a synopsis of the current 'fracking-related' public and workplace safety and health research, and

- Discusses safeguards drilling companies need to consider in anticipation of the wells finally being exhausted (or becoming uneconomic to operate).

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Shale gas and the Practice of Hydraulic Fracturing

US Energy Information Administration (USEIA) (2012) defines shale gas as the natural gas trapped in shale formations, petroleum and gas rich sedimentary rocks; very fine grained sandstone (King 2012). The practice of extracting shale gas [hydraulic fracturing] has been around since the 1940's. And while the practice has been known about since 1800s the first hydraulic fracturing (or 'fracking') experiment was carried out in 1947 and the process became commercially viable in the 1950s (King 2012). Hydraulic fracturing is the practice of drilling a well into the core of the shale, at significant depths, sometimes as deep as 2 - 3km (BGS 2011). A high-volume of highly pressurised fluids[frac fluid], a combination of water, sand and chemicals, is used to fracture the shale rock, which allows for the release of the shale gas. The rate of release of the gas is controlled by the use of a proppant, a substance used to keep an induced fracture (or frac) open.

The frac fluid is not a standard fluid, with many companies using a proprietary substances, for which they maintain a 'commercial confidence' right to withhold the full specification. Concerns are expressed that the nature of the proprietary fluids is such that they could harbor hazardous substances (quantities unknown). There are moves by the Environment Protection Agency in USA to have law amended to require companies to fully disclose their safety data sheets, however at present this is voluntary. A report provided to US House of Representatives (2011) concluded;

> *"[Hydraulic fracturing] has opened access to vast domestic reserves of natural gas that could provide an important stepping stone to a clean energy future. Yet questions about the safety of hydraulic fracturing persist, which are compounded by the secrecy surrounding the chemicals used in hydraulic fracturing fluids."*

A study by Cooley and Donnelly (2012) identified a commonality to the broad range of concerns regarding hydraulic fracturing. Acknowledging their small sample size, although happy with the broad nature of the target groups, Cooley and Donnelly (2012) identified that air and water quality featured heavily in list of concerns. Community aesthetics and increased traffic flows were well represented, while worker health and safety and seismic activity barely featured in the list of concerns. Rich (2009) confirmed in an air monitoring study of several locations in the town of DISH, Texas the presence of multiple Recognized and Suspected Human Carcinogens. Rich (2009) concluded that the identified compounds usually associated with industrial processes such as exploration, drilling, flaring and compression common to the natural gas industry. Lechtenbohmer et al (2011), in a report to the European Parliament, were advocating the need for a reassessment of the full impacts from hydraulic fracturing. They concluded that there were a wide range of conceivable accident risks such as; "*blow out with frac-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). And these, they argue, could 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 the consequent increase in the frequency of accidents. The USA experience supports such an analysis (Lechtenbohmer et al 2011). However their report was not entirely negative in its conclusions, indicating the authors' belief that these risks can be reduced and probably avoided with adequate technical directives, cautious handling practice and supervision by public authorities (Lechtenbohmer et al 2011).

Ewen et al (2012) in a study carried out by a panel of experts in conjunction with ExxonMobil's hydrofracking dialogue and information dissemination process concluded that there was no need for an outright ban on the practice of hydraulic fracturing. Acknowledging that up until now several unknowns exist with regard to the environmental and health impact of the process Ewen et al (2012) suggest proceeding with caution, not whole scale. The following elements, they argue, are necessary if the process is to proceed; "*a defined state of the art; a legal framework that addresses the new risk dimension entailed by hydrofracking; and additional scientific knowledge*". For the time being, they continued; "*all that should be made possible is exploration of gas fields and realization of single model projects, for which extensive safety precautions should be taken and the scope of investigations and testing should be expanded*". Other studies, not so directly aligned to the oil exploration industry suggest a more cautionary approach, calling for further regulatory controls or an outright ban. Wiseman (2009) argues for a comprehensive national survey the environmental effects of fracing that is scientifically rigorous.

Wiseman (2009), acknowledging the good work being carried out by some of the oil and gas companies as technology advances, suggests that, in the light of such concerns and while studies are in progress, Congress should reconsider exempting fracking from the Safe Drinking Water Act. States should review whether general regulation of the oil and gas industry adequately addresses the potential public health and environmental impacts, Wiseman (2009) also argues. Lechtenbohmer et al (2011) indicated that, "*some risk is inherent to uncontrolled fracturing which results in uncontrolled mobilization of fracture liquids*". For instance, they maintain, it is well known that "*small earthquakes can be induced by hydraulic fracturing which might mobilize gas or fluids through "naturally" created fractures*". Seismic activity was explored, following minor tremors were detected near the Presse Hall well near Blackpool, UK. Green, Styles and Babtie (2012) in their report to the UK's Department of Energy and Climate Change (DECC) acknowledging that the seismic activity could be directly attributed to fracking activities, made the following recommendations;

1. Hydraulic fracturing procedure should invariably include a smaller pre-injection and monitoring stage before the main injection.

2. Hydraulic fracture growth and direction should be monitored during future treatments

3. Future HF operations in this area should be subject to an effective monitoring system that can provide automatic locations and magnitudes of any seismic events

in near real-time.

4. Operations should be halted and remedial action instituted, if events of magnitude 0.5 M_L or above are detected.

They further recommended that for any future sites identified for hydraulic fracturing that base line seismic assessments be made prior to any industrial activity commencing. Consequently UK fracking operations are paused (BGS 2011) not banned. UK Government sees no need for a moratorium. This concurs with the work of Williams (2012) where he notes the requirements within the Legislation and Policy Framework for the Queensland Government. It is a requirement that notification be given to landowners prior to commencing and after cessation of operations and that that notice, as well as specifying the chemicals used and the volume of same, must also provide details of completed seismic surveys.

Worker health and safety is largely under represented in the research carried out into the hydraulic fracturing industry operations thus far. Health and Safety Executive (HSE) in the UK have regulatory responsibility for well design and construction, which among other things requires independent verification of the well design. Further scrutiny is afforded through local planning process, the environmental protection agency's consideration of environmental impacts, and the obligation on operators to disclose the content of their fracing fluids. However with issues of public health to the fore along side environmental concerns it is remiss to exclude the health and the safety of those at the 'coal-face'. Bernard Goldstein, a professor in the Graduate School of Public Health at the University of Pittsburgh (cited in Schmidt, 2011) says, "…*published epidemiologic studies relating shale gas production to health are virtually nonexistent*". There are many hazards identified to which the degree of exposure and the extent of appropriate hazards controls ought to be addressed. The Royal Society and the Royal Academy of Engineering (RAE) (2012) consider that health, safety and environmental risks "*can be managed effectively in the UK as long as operational best practices are implemented and enforced through regulation*". RAE (2012) suggest a means of collating and sharing best practice information, the engagement of the regulatory authorities (in UK) and support the use of the Research Councils to further research. The unfortunate omission in the list of priorities was worker health and safety as they suggest research should include "*the public acceptability of the extraction and use of shale gas in the context of UK policies on climate change, energy and the wider economy*" (Royal Society and RAE, 2012). As the debate into fracking progresses and the decision as to whether it should continue research into the ability to control worker safety and health by engineering controls and through managerial procedures must take a higher priority. Such due diligence is a fundamental aspect of the engineers' code of ethics, enshrined in the International Engineering Alliance (IEA)'s Washington, Sydney and Dublin Accords (IEA 1989, 2001, 2002).

Workplace Hazards Associated with Hydraulic Fracturing

Respirable Crystalline Silica and other Health Hazards

In reviews of occupational safety and health hazards associated with hydraulic fracturing, health and in particular worker exposure to respirable crystalline silica was the dominant hazard discussed. Crystalline has long been recognized as a carcinogen (NIOSH 2010). To cause lasting damage the form of silica must be of a respirable particle size to enter the deep lung. The United States Occupational Safety and Health Administration (OSHA) and National Institute for Occupational Safety and Health (NIOSH) have identified respirable crystalline silica as a worker health hazard during the hydraulic fracturing processes (OSHA, 2012; Esswein et al., 2012b). NIOSH began thier worker health exposure characterization effort in January 2010 (NIOSH, 2010). OSHA regulates exposures to crystalline silica via a Permissible Exposure Limit (PEL). Because OSHA PEL's are not updated frequently, NIOSH produces a Recommended Exposure Limit (REL) based on more current toxicological data; thus the REL is more stringent than the OSHA's PEL. In a recent personal air sampling research, Esswein et al. (2012a) took 116 employee breathing zone samples for respirable crystalline silica at 11 hydraulic fracturing sites and found 47% above the OSHA PEL and 79% above the NIOSH REL. In addition they found that 31% of thise surveyed were 10 times above the NIOSH REL (Esswein et al., 2012b).

Esswein et al. (2012a) found that sand can be used in amounts up to 4 million pounds per well, and exposures occurring mostly in cementing jobs, sand transferring, and sand loading. From a review of the Esswein et al.'s presentation (2012a) and the OSHA and NIOSH reports, it does not appear these are new operations. In other words, the fracturing process is simply using a known carcinogen in traditional ways (cementing, transferring, and loading). Hydraulic fracturing operations need to utilize occupational safety and health range of control to solve this known problem. Esswein et al. (2012a) also found worker exposures to other chemicals during the hydraulic fracturing process including the following: diesel particulate; volatile organic compounds; hydrogen sulfide (H2S); hydrochloric acid gas; aldehydes; and lead. Although in their report, it is not clear whether overexposures existed to these substances occurred in any of the worker's personal breathing zones (Esswein et al. 2012a). The findings and recommendations focused on repairable crystalline silica.

Site clearance / preparation

Before drilling and extraction processes the site must be cleared and prepared for heavy equipment to install the hydraulic fracturing systems. Pipelines might also be installed. Potential worker safety and health hazards in this stage would be indicative of those associated with forestry operations, logging, site grading, and trenching (Marcellus Shale Corporation, 2012).

Hydraulic Fracturing Processes / Construction of wells

No specific literature or reports have been found that focus on worker safety hazards specific to the installation of the hydraulic fracturing process, its operation, or decommissioning. The safety and risks of these operations must be further studied to determine if new or unique hazards exist and to recommend control measures to the industry. From a review of the fracturing processes, the risks of explosions, and the general exposures to heavy equipment and truck traffic risks exist. It is not known whether these are increased compared to general mining and construction activities. Injury attorneys are naturally seeking to get in on the hydraulic fracturing business. For example, one attorney in Pennsylvania, where the large Marcellus gas deposit sits, focuses on injuries and recognizes that the rush for the gas can contribute to worker fatigue. From their website, "The Marcellus Shale gas rush has made a lot of money for the oil and gas companies, as well as local contractors and workers in the fracking industry. Yet too often, worker safety is a secondary concern when there is so much pressure to work fast and keep the gas flowing (Huber and Palsir, 2012). They label these accidents, "*fraccidents*", and go on to describe two recent claims. They "*represented a worker who fell from a ladder onto a drilling unit, resulting in an elbow displacement fracture. In another case, piping was tied down with a snap binder so tight that it exploded in our client's face, causing an orbital socket injury and brain trauma*" (Huber and Palsir, 2012).

Ethics Reflections on Hydraulic Fracturing

Following on from the financial scandals of the early 2000s that saw the collapse of several large financial institutions, [Enron, Worldcom, Anderson] corporations are expected to conduct their affairs in an ethical manner taking into consideration the interests of all their stakeholders, not solely those of the shareholders. To this end the Organisation for Economic Cooperation and Development (OECD) issued in 2004 their Principles for Corporate Governance, which over the subsequent years has come to be the guide for all types of corporations and businesses on their financial and societal obligations. The obligation to manage the affairs of the hydraulic fracturing business, like any other business, in a sustainable manner that ensures continued economic success and growth in the interests both of the company and of the nation is at the core, but in parallel is an ethical obligation to those who are effected by the undertakings of the business; namely customers, employees, the communities in which the business operates, the state and in relevant cases the wider society when it is effected by what the business does or fails to do.

Ethical codes are now a common place in many businesses whether stated as core values, a statement of ethics, or other policy on financial integrity, corporate social responsibility or environmental commitment. The validity of an ethics code is tested against three criteria; that the code, in the context of the whole of the business is self-consistent, that it is good for humanity (Fromm 1947) and that it is capable of universalisation, (Crain 1985, Eckensberger 2007). Self-consistency requires that there are no logical contradictions arising from the various elements of the code, including the company's policies, objectives and mission statements. The fact that a company does not adhere to its own code is not a negation of the self-consistency of that code, but rather evidence of non-compliance and unethical behaviour by the company. Contradictions arise for example when the legal requirements of contracts of employment conflict with the professional duties of engineers to prioritise their obligations to the wider society (IEA Accords 1989, 2001, 2002). Companies expect and reward loyalty and it is considered good ethical behaviour to work (in full compliance with the law) in the interests of the employer. But when the interests of the employer is not fully accepted by the communities in which they operate, professionals seek ways to mitigate the contradiction between conflicting duties. The EUCI Conference on Engineering and Technology Developments (2012) included an agenda item to explore potential risk management strategies with the aim of avoiding costly permitting delays and for reducing potential litigation risks. Though the outcomes of such deliberations may lead to strategies that will benefit external stakeholders and the environments, the terminology used clearly implied an economic objective on behalf of the extraction companies and that any benefits to other stakeholders or the environment would be incidental. The function of ethics is that it is concerned with guiding behaviour such that at its most basic it will not harm others and in its more evolved forms actively contributes to the good of others. The OECD principles at their core aims to have companies behave with financial integrity and in the interests of their shareholders. But they recognise too that companies in their undertakings have an impact on other stakeholders and that these interests must be considered and acted upon whenever harm is a real outcome. The more directly affected by the undertakings of a company the more their interests become of immediate concern. The nature and extend of the undertakings of the extraction companies is such that large population centres, extensive rural communities, underground and surface water sources extending tens and hundreds of miles from well and quarrying activities are all effected (Blohm et al. 2012, Haworth et al. 2012) and that the key stakeholders constitute a substantial proportion of the current and future populations in countries where these activities are undertaken.

There is evidence that the economic and social advantages to be gained from coal-bed methane extraction (CBM) will be extensive. Many $billions will be generated, tens of thousands of jobs will be created and a key political issue will be energy security for the next generation, (Considine et al. 2011, Tieman et al. 2012). However when these economic benefits compete with public concerns about water contamination, landscape destruction and air pollution (Haworth et al. 2012, Osborn et al. 2011) it is not sufficient to pour money into lobbying the law-makers to pass legislation that favours the extraction companies to the detriment of the interests of local communities. In 2011 a single extraction company spent $1.09m on a single issue compared to $480,000 by the Citizens Campaign for the Environment on all their lobbying issues, (Lerner 2011, Browning & Kaplan 2011). Disproportionate expenditure on lobbying may benefit the shareholder but it leaves the remainder of the key stakeholders to live with the consequences. In Australia one organisation views coal-seam gas (CSG) as but another activity on the land and in the landscape that requires management (Williams 2012). Recognising the potential significant negative impact on water resources, and that protection of the biodiversity and landscape is critical but a neglected national resource issue their proposals are that CSG production and agricultural and forestry protection needs to be approached holistically and managed as part of whole landscape planning, (Williams 2012). There is an element of realism here that 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, but integrated fully 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. The causes of the earthquakes in 2011 near Blackpool, UK, thought o be attributed to direct fuel injection into adjacent fault zones during treatment projected a low probability for further earthquakes. Green, Styles and Baptize (2012) were unconvinced of these projections basing their conclusions on the fact that the earlier reports had failed to identify a causative fault and that details knowledge of faulting in the area was poor. The recent jailing of Italian scientists (Halsbury's Law Exchange 2012) for failing to predict earthquakes is a salutary lesson that competent objective assessments uninfluenced by political or economic considerations is the minimum that is to be expected from companies and their consultants.

Failure to properly examine the concerns of effected communities and allow extraction practices to continue without adequate regulation will not satisfy the complainant, even when the democratic organs have carried out the assessments. The US's Environment Protection Agency report (2004) into contamination of underground sources of drinking water (USDW) concluded that injection of hydraulic fracturing fluids into CBM wells poses little or no threat to USDWs and that there was no justification of further study at that time. In respect of complaints of contamination, they saw no conclusive evidence that water quality degradation was due to hydraulic fracturing, but that several other sources may be responsible. That report was based on existing literature and on incidents complaints of drinking well contamination. An objective specific study focussing on the particular issue was not commissioned, however by 2011, when over 1,000 complaints had been received the EPA was required by government to fund a new study to examine cases of contamination, (Lerner 2011). A mature ethic requires that where harm is occurring or is alleged, studies into the causes must have as a priority the interests of those on whom the harm is falling. Failures in this regard or partisan approaches to investigations is a negation of ethical behaviour and of the positive economic opportunities presented by they processes.

Ultimately, a code of ethical behaviour must have universalisability, namely that it underscores the fundamental value of equal existence (Kohlberg, cited in Crain 1985) and recognising that that takes precedence over claims to property or wealth rights, or of national energy security issues. Such rights and issues gain validity only in the context of being subordinate to achieving universal equal existence. In this respect it is incumbent upon the industry to consider in their impact assessments how this is to be achieved, how the environment is to be protected, how contamination of the water and air resources is to be prevented and how the production of gases is to contribute to human welfare and sustainability.

Economic Reflections on Hydraulic Fracturing

The extraction of natural gas from shale formations is one of the fastest growing trends in American on-shore domestic oil and gas production (Ground Water Protection Council, cited in Jackson et al 2011). USEIA (2011) estimate that there is 750 trillion cubic feet (tcf) of technically recoverable shale gas resources in 3 regions of USA, North East, Gulf Coast and 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 North East Region of USA, compared with INTEK's estimate or 410 tcf (cited in USEIA 2011). Williams, Stubbs and Milligan (2012) report that while Australia has large coal seam gas [shale gas] potential, exploration is in its infancy consequently resources are, as yet, poorly understood and quantified. Nevertheless Queensland Government has indicated that in their state alone the coal seam gas [shale gas] industry will generate over 18,000 jobs and net annual royalties in the order of AUD$850m. In UK British Geological Survey (BGS) (2011) has estimated the UK shale gas reserve potential could be as large as 5.3 TCF.

Priddle (2012) reports "*producing unconventional gas is an intensive industrial process, generally imposing a larger environmental footprint than conventional gas development*". Often more wells are needed and hydraulic fracturing is usually required to boost the flow of gas from the well. In the face of all predictions of economic prosperity offerd by hydraulic fracturing the diverse nature of economic benefits claimed the discussion, kept simple, can be advanced by asking the '5W' questions from an economic perspective, namely, Why, What, When, Where and Who. An intriguing tapestry regarding fracking can be created from the simplest premise;

1. Why fracking, well why not?
2. What can fracking provide for humanity from an economic perspective?
3. When will the costs and benefits of fracking be realised?
4. Where does the value to humanity lie in the practice of fracking?
5. Who are the potential winners and losers from the practice?

Why Fracking or similarly why Nuclear or any other form of energy provision; all have potential repercussions if they go wrong but the argument for the use of fracking is that even though it is potentially risky the potential benefits can be argued to far outweigh the potential costs. Considine et al (2011) argues that the US has shale gas reserves large enough to satisfy US demand for decades or centuries to come. The report also postulates that the support activities such as steel, sand and gravel supply and engineering services to the shale gas extraction projects are not easily outsourced to foreign suppliers so the local economy and workforce is largely going to benefit. Considine et al (2011) concludes that shale gas production can offer regions a stream of revenues that doesn't quickly dry up quoting figures of $4,000,000 on average in economic benefits from each well. Compare this with Lechtenbohmer et al (2011) report for the European Parliament that concludes that in a time when sustainability is key it should be questioned whether the injection of toxic chemicals into the ground should be allowed or banned in Europe. This is further reinforced in that the report also indicates that the potential shale gas plays are too small to have an impact on the European gas supply.

This brings the discussion to Cost Benefit Analysis (CBA) as a means of justifying the practice. Who prepares the CBA and for whose benefit and at whose cost? It could be argued that potentially the organisation that prepares the CBA may not be able to be truly impartial due to the specialist nature of the practice. Lechtenbohmer et al (2011) argue that Life Cycle Analysis (LCA) should be mandatory and that consideration should be given to including a CBA as compulsory based on an extensive LCA for each individual project. This they maintain is necessary to demonstrate the benefits for society as a whole.

This also brings to the fore the point of value for money and return on investment (ROI). No government or organisation no matter how wholesome the image they appear to present, are in the business of not getting value for money and a ROI that matches or exceeds their shareholders or voters expectations. Fracking from a headline point of view seems to have very few friends around the world but it is no accident that those who generally are in favour of the practice are those who will benefit financially. Taking a generalist big picture viewpoint on Considine et al (2010) and Lechtenbohmer et al (2011) are at opposite ends of the spectrum, with Considine et al (2010) arguing from a US standpoint, very much in favour of the benefits of and apparent lack of environmental costs of fracking. Lechtenbohmer et al (2011) posting a more guarded cautious approach to fracking within the European Union, concluding that the large gaps in EU regulation with regards to fracking need to be addressed before any decision to move forward in a substantive manner and also highlighting the need for full awareness of the potential massive environmental and human impacts. The US based report (Considine et al 2010) on the other hand whilst identifying possible environmental impacts considers them as such a low risk that when applying CBA techniques they indicate an average cost of $14,000 per well as opposed to $4million of benefits per well. However there is insufficient evidence to corroborate these assertions. The key final recommendation from Lechtenbohmer et al (2011) was with regards to much tighter regulation to reduce the possible costs to the environment and population to a minimum. Lechtenbohmer et al (2011, p.79) concluded that;

> *"Because of the complex nature of possible impacts and risks to the environment and to human health of hydraulic fracturing, consideration should be given to developing a new directive at European level regulating all issues in this area comprehensively".*

One final question is how two relatively opposing viewpoints can exist on the same process, which is simple to answer on the premise that there are a least three sides to every story, namely, the for side, the against side and the real truth somewhere in between. Ultimately then where does the economic truth with regards to fracking lie?

Future Research

The list of questions under each heading could be virtually endless but this only goes to reinforce the need for further critical research into the field of hydraulic fracturing from OSH, ethics and economics perspective. Not surprisingly this preliminary scoping exercise has raised more questions than answers which from a review of the existing knowledge of fracking practices appears to be a practice that for Governments deciding on whether to develop their Fracking agendas should take time to consider and demand independent answers on a case by case basis. Fracking is certainly not a process where one approach fits all or benefits all localities and communities with or without appropriate regulation.

Compared to worker health, there appears to be a gap in worker safety research during the preparation, installation, and operation of hydraulic fracturing processes. The safety and risks of these operations must be further studied to determine if new or unique hazards exist and to recommend control measures to the industry. Researchers should seek opportunities to work with drilling companies, developers, and workers to adequately describe the nature of safety related hazards and risks in hydraulic fracturing and through a consideration, using the established approaches to prevention through design, value engineering/ CBA and cultural maturity indexing establish the efficacy of elimination or mitigation of OSH hazards. Research should focus on equipment manufacturers and the design of individual wells. In the interim engineering controls, training, and enhanced procedures should be developed and communicated within the industry.s

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