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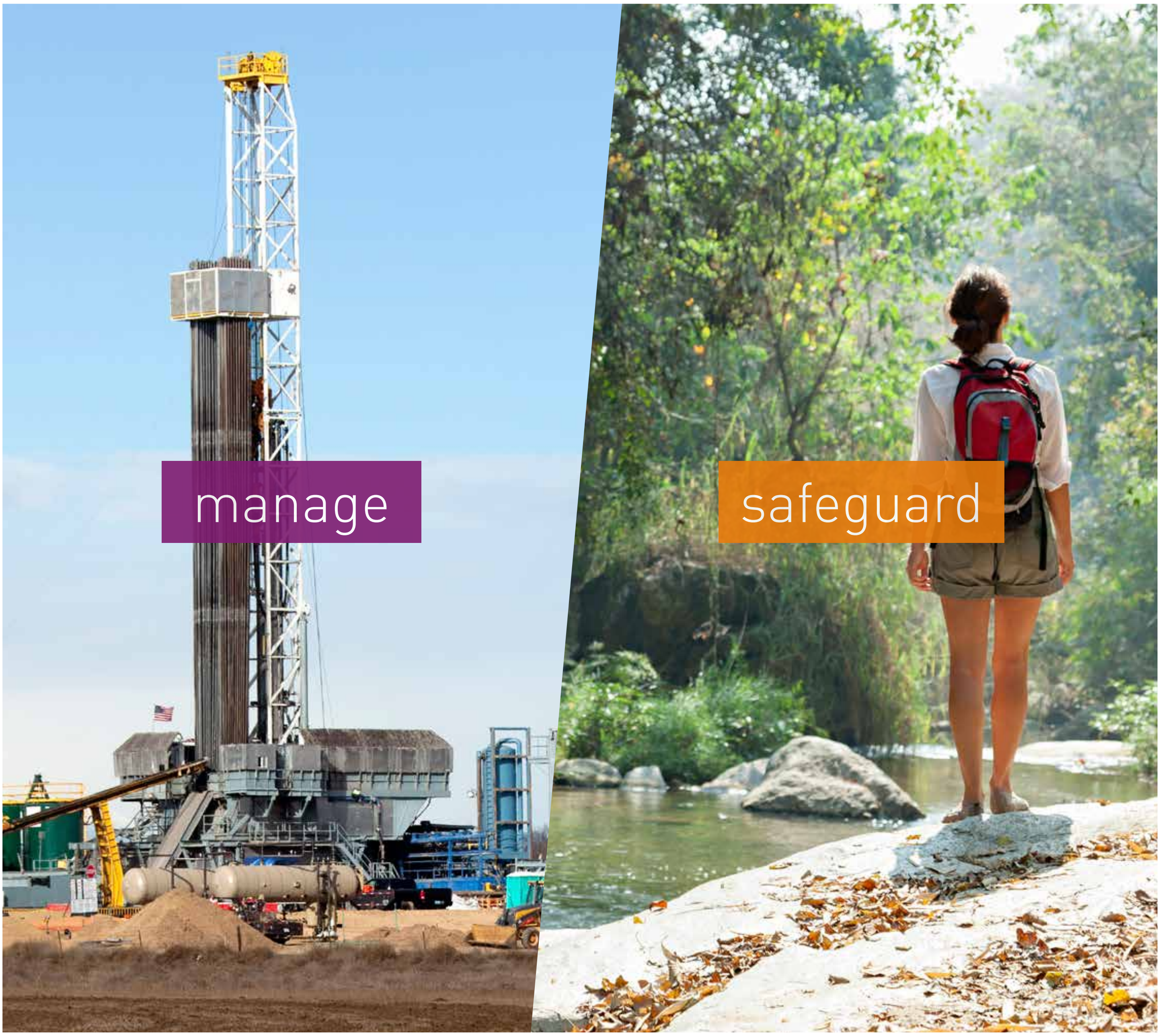
EUROPEAN OILFIELD SPECIALITY CHEMICALS ASSOCIATION

REPORT 553

APRIL 2016

Generic exposure scenario for the use of chemicals in the exploration and production of hydrocarbons using high-volume hydraulic fracturing



Acknowledgements

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Generic exposure scenario for the use of chemicals in the exploration and production of hydrocarbons using high-volume hydraulic fracturing

Revision history

VERSION	DATE	AMENDMENTS
1.0	April 2016	First release
1.1	May 2016	Update to 'Related use descriptors', page 6.

Foreword

This report assesses the level of environmental exposure to the chemical products used in the exploration and production of hydrocarbons using high-volume hydraulic fracturing – such as shale gas.

It is divided in two parts:

1) The SpERCs (Specific Environmental Release Categories) factsheet contains the relevant data. It includes detailed information on the emission factors and operating conditions for the use of a substance in high-volume hydraulic fracturing.
2) The background document adds further information about hydraulic fracturing operations and the use of chemicals. It describes the main phases of a hydraulic fracturing operation providing with a detailed analysis of the operating conditions. This includes a section devoted to the use of the different types of fracturing fluid.

The report covers environmental emissions during the exploration and production of hydrocarbons (such as shale gas) using high-volume hydraulic fracturing. This includes the handling of fracturing fluid products and proppants during a hydraulic fracturing operation from the arrival of the substances on the site to the end of well clean up when production starts. It does not cover the use of chemicals in exploration and production activities other than high-volume hydraulic fracturing nor site preparation and well abandonment. It is assumed that all of these activities are likely to take place at an onshore exploration and production site which will be developed according to stringent standards in order to minimize emissions to air, water and soil.

The report was developed jointly by the International Association of Oil & Gas Producers (IOGP), the European Oilfield Specialty Chemicals Association (EOSCA) and the European Chemical Industry Council (CEFIC).

Contents

Factsheet

FS Section	Expected types of information
Title of SpERC	**Exploration and Production of Hydrocarbons Onshore Using High-Volume Hydraulic Fracturing**
SpERC code	SpERC Code TBC ERC4
Scope	• Substance types / functions included or excluded: Applicable to substances performing all functions in onshore high-volume hydraulic fracturing fluid including proppant. Excludes all other activities, such as site preparation and drilling. • Inclusion in matrix No • Specification of product types covered Wide range of product types performing various functions required for hydraulic fracturing fluid. • Additional information Release of proppant is included to cover the eventuality that the substance in question is a component of coating used to improve the property of the sand/ceramic base.
Process description	• Description of operation: Activities within the scope of the SpERC include: transfer of chemical and proppant from transport and storage vessels; fracturing fluids preparation; pumping; sampling; recovery of flowback and process water (recovered water), treatment of recovered water and cleaning of equipment. • Processing steps /activities where the main emissions occur Small losses to air may occur during each activity described above. During operations, losses to water and soil are confined by, for example an impermeable lining to the production site (see Operational Conditions). Where substances in recovered water are treated via a waste treatment plan there is potential for emission to surface water.
Related use descriptors	**Identified Use Name**: "Hydraulic fracturing for oil and gas exploration or extraction" **Sector of end use**: SU2a (onshore) or SU2b (offshore) **Process Category**: PROC 1, PROC2, PROC3, PROC4, PROC8a, PROC8b *Note - proposals to change the scope of PROCs 1-4 have been made that would no longer cover this scenario, but industry does not agree with these changes.* **Product Category**: PC41 "Oil and gas exploration and production products" **Environmental Release Category**: ERC4

FS Section	Expected types of information
Operational conditions (including information on technical strategies to achieve high raw material efficiency)	• Location of use: Outdoor use. • Degree of containment of the main process: The main process is closed, being contained within tanks, pipework and valves. The integrity of containment of the closed system above-ground is essential for maintaining the high pressures required to conduct high-volume hydraulic fracturing. • Water contact: Fully formulated hydraulic fracturing fluids are water based. • Automation in chemicals handling influencing raw material efficiency: Fracturing fluid components are transferred and mixed using controlled systems. • Measures to achieve efficient use of chemicals: It is anticipated that recovered fluid, will be treated and re-used for subsequent fracturing operations. • Conditions of equipment cleaning: Equipment cleaning would be water based. Water used, for example, to flush pipe-work, may be collected and re-used for subsequent fracturing operations. • Conditions of auxiliary processes, if relevant for release: Not applicable. • Conditions preventing emissions to air: Activity takes place in closed systems therefore emissions to air are minimal. It is not expected that specific RMMs are installed to prevent such emissions from taking place. • Conditions preventing emissions to water: Emissions to surface water are prevented through the design of the installation. By way of example spills, leaks and cleaning solutions may be drained to a lined storage area, preventing release to surface water. Sub-surface releases of fluid during the fracturing process are prevented from reaching aquifers through the presence of relatively impermeable formations above the target formation. This limits upward migration of fluid. This is also relevant to recover fluid that is re-injected for use or disposal. A minimum vertical separation distance between the target formation and aquifer should be respected. National legislation may also require a minimum depth (e.g. the UK's Infrastructure Act proposed prohibition of fracturing at depths of less than 1000m). See IOGP, CEFIC, EOSCA, 2015.

FS Section	Expected types of information
	Recovered water may finally be discharged via one or more large-scale waste water treatment plants where a combination of physical and biological treatments will reduce emissions to the receiving water. • Conditions preventing emissions to soil: Emissions, through downward migration are prevented through the design of the installation. By way of example spills, leaks and cleaning solutions may be prevented from downward migration to soil by the employment of a non-permeable membrane below the well pad. Sludge from treatment works should not be spread on land. • Existence of standard municipal STP Waste contractors employed to dispose of recovered water, may do so via a waste water treatment plant, depending on the properties of the water and conditions of local regulations. Assumed treatment plant capacity = 20000 m^3 /day (see IOGP, CEFIC, EOSCA, 2015). • Qualitative information on how waste from equipment cleaning is handled Contaminated water arising from cleaning will be collected and removed for disposal according to EU and local regulations and conditions. • Qualitative information on how processing waste is disposed of: Waste product remaining in containers after use will be returned, in the containers, to the supplier for cleaning/refilling. • Qualitative information on which types of waste occur from RMMs and how they are disposed of: Waste sludge from treatment works will be handled as industrial waste and not spread on land.

FS Section	Expected types of information
Obligatory RMMs onsite	• RMM limiting release to air: Not applicable. • Air RMM Efficiency (differentiated according to substance properties, if sub-spERCs are defined): Not applicable. • Reference for Air RMM Efficiency: Not applicable. • RMM limiting release to water: Construction of installation to include, for example, a continuous impermeable lining that prevents possible surface leaks and spills to water. Large scale waste water treatment works for final discharge of recovered water. • Water RMM Efficiency (differentiated according to substance properties, if sub-spERCs are defined): -RMMs through design of installation are 100% efficient -Removal of substance in recovered water at a treatment plant will be substance specific depending on substance properties such as biodegradability, adsorption coefficient and volatility. • Reference for water RMM Efficiency: 2014/70/EU COMMISSION RECOMMENDATION • RMM limiting release to soil: Construction of installation to include, for example, a continuous impermeable lining that prevents possible surface leaks and spills to soil. • Soil RMM Efficiency (differentiated according to substance properties, if sub-spERCs are defined): RMMs through design of installation are 100% efficient. • Reference for soil RMM Efficiency: 2014/70/EU COMMISSION RECOMMENDATION

FS Section	Expected types of information
Substance use rate	Daily substance use rate during regular processing, differentiated according to substance functions. Chemical substance as fracturing fluid = 2000 kg A generic tonnage of chemical substance used in hydraulic fracturing has been taken to be 2000 kg per site based on a use rate of 0.03% substance in total fracturing fluid (water + proppant+ chemical substances). If a registrant is aware that the final concentration of substance is different to this, the tonnage may be scaled accordingly. - Chemical substance as waste = 115 kg* per day for 13 days *Based on 75% of 2000 kg chemical substance returned as waste and discharged over 13 days (see below for estimation of emission days) - Proppant coating as fracturing fluid = 23 tonnes Assumes that coating comprises up to 5% of total proppant weight. Proppant coating as waste = 0 kg see IOGP, CEFIC, EOSCA, 2015 for justification of generic values
Emission days	Number of emission days during regular processing: - Chemical substance as fracturing fluid days - Chemical substance as waste = 13 days* - Proppant = 2 days * volume of fracturing fluid [6633 m^3] x fraction returned [0.75] / daily volume of returned water [382 m^3/d] see IOGP, CEFIC, EOSCA, 2015 for justification of generic values
RF air	Numeric value / percent of input amount: -0.95% if water is disposed of via re-injection to disposal well. -1.25% if waste-water is re-used or disposed of via treatment works.
Justification RF air	IOGP, CEFIC, EOSCA, 2015.

FS Section	Expected types of information
RF water	Numeric value / percent of input amount: -0% for operations not discharging to a treatment plant -75% for operations that finally discharge recovered water via a treatment plant. *Note:* *Release fraction (75%) is BEFORE removal through treatment at a plant.*
Justification RF water	IOGP, CEFIC, EOSCA, 2015.
RF soil	Numeric value / percent of input amount: 0%
Justification RF soil	IOGP, CEFIC, EOSCA, 2015.
RF waste	Numeric value / percent of input amount: 0%
Justification RF waste	IOGP, CEFIC, EOSCA, 2015.
Optional RMMs	Indication that information on RMMs is provided in the background document Not applicable
Scaling	Scaling equation and parameters that can be scaled Daily use should not exceed that indicated in the exposure scenario.

References

IOGP, CEFIC, EOSCA, 2015. Background Information Document Supporting The Generic Exposure Scenario For The Use Of Chemicals In the Exploration And Production Of Hydrocarbons (Such As Shale Gas) Using High Volume Fracturing.

2014/70/EU COMMISSION RECOMMENDATION on minimum principles for the exploration and production of hydrocarbons (such as shale gas) using high-volume hydraulic fracturing. Jan 22 2014.7 Installation design and construction

Background information document supporting the generic exposure scenario for the use of chemicals in the exploration and production of hydrocarbons (such as shale gas) using high-volume hydraulic fracturing

1. Introduction

On 22 January 2014, the European Commission released a recommendation for 'Minimum principles for the exploration and production of hydrocarbons (such as shale gas) using high-volume hydraulic fracturing' (2014/70/EU) [1]. Member States have been invited to implement these recommendations for a sustainable development of hydraulic fracturing activities. The EU chemicals regulation, REACH, provides a framework for environmental exposure assessments which covers the entire life cycle of a substance, including its use during the hydraulic fracturing activity.

Recognizing the public, political and industry interest around the use of hydraulic fracturing in the exploration and production of hydrocarbons (such as shale gas), IOGP, EOSCA and Cefic drafted this report to support the development of a generic environmental exposure scenario for fracturing fluid products. Onshore exploration and production of hydrocarbons (such as shale gas) can be undertaken in an environmentally sound way.

The technology used in high-volume hydraulic fracturing is well established and industry has been using and developing this and similar techniques for decades. The composition of a fracturing fluid and treatment regime will be dependent on the well design and the properties of the reservoir being fractured. The injection stage of the fracturing process takes place over a relatively short period of time (typically less than one week) but treatment may occur in stages over a number of weeks and may be repeated if reservoir productivity declines.

Experience demonstrates that effective implementation of current legislation, guidelines and established industry practices minimizes potential environmental releases.

It is important that industry and authorities maintain a dialogue and cooperate to address public concerns through the transparent sharing of information and knowledge. IOGP, EOSCA and Cefic are key supporters of ngsfacts.org [2] which provides a platform for industry within the European Economic Area to voluntarily disclose fracturing fluid products on a well by well basis.

This report is the basis for the environmental exposure assessment for the use of chemicals in hydraulic fracturing activities. It shows that, under the conditions of use described in this report, and provided that current legislation, guidelines and established industry practices are followed, potential environmental releases are minimal and manageable. This ensures that the environment is safeguarded.

Whilst chemical substances used in high-volume hydraulic fracturing are already subject to the requirements of REACH, IOGP, EOSCA and Cefic will continue to cooperate with the EU Commission to improve REACH registration dossiers (where required) and raise awareness of how the REACH regulation applies to substances used within fracturing fluid. The parties have thus jointly and proactively drafted a Specific Environmental Release Category (SpERC)[1] and this report to support the Generic Exposure Scenario for the use of chemical substances in the exploration and production of hydrocarbons (such as shale gas) using high-volume hydraulic fracturing.

[1] Exposure Scenarios describe how substances may be safely used to control exposures to human health and the environment (i.e. including the necessary operational conditions and risk management measures). Generic Exposure Scenarios are exposure scenarios applicable to the general use of substances within a specific sector (in this instance, the use of chemicals in the exploration and production of hydrocarbons such as shale gas using high-volume hydraulic fracturing). Exposure Scenarios and Generic Exposure Scenarios take into account Environmental Release Categories (ERCs) and Specific Environmental Release Categories (SpERCs). SpERCs describe the broad conditions of use of a substance from an environmental perspective and potential environmental emissions associated with that use. SpERCs refine the ERCs for a specific industrial use and provide for more accurate assessment of potential environmental emissions.

2. Scope of Generic Exposure Scenario according to REACH

Under the REACH regulation, human health and environmental exposure scenarios are required for all relevant uses of a registered substance for which a chemical safety assessment[2] is required, i.e. the substance is hazardous to human health or the environment. Human health exposure scenarios for substances used in high-volume hydraulic fracturing are, however, the same as those for other industrial processes using the same substances. Standard human health exposure scenarios for industrial applications are contained in substance registration dossiers and are therefore not included in this report.

The purpose of this report is to develop an environmental exposure scenario, and describe the emission factors and operating conditions for the use of a substance in high-volume hydraulic fracturing. This information is packaged in a SpERC, which allows for a standardized assessment of the risks associated with the generic use of substances in a specific industrial application.

This report presents the background information used to develop the SpERC for the use of chemicals in the exploration and production of hydrocarbons (such as shale gas) using high-volume hydraulic fracturing.

The following generic points further define the scope for this SpERC:

1) REACH only covers operations under normal circumstances. Possible emissions through accidents (such as wellbore integrity loss or aboveground spills) are covered under other specific European and national regulations, i.e. health and safety legislation, licensing, permitting and planning requirements.

   REACH does not cover biocidal actives – these are covered by the Biocidal Products Regulation. However biocidal products may be used in high-volume hydraulic fracturing and, while a REACH exposure scenario will not be required for these actives, the assumptions and exposure scenario parameters in this report are relevant.

[2] The Chemical Safety Assessment (CSA) is the process that identifies and describes the conditions under which the manufacturing and use of a substance is considered to be safe [3].

2) This report covers the environmental emissions during the exploration and production of hydrocarbons (such as shale gas) using high-volume hydraulic fracturing. This includes the handling of fracturing fluid products and proppants during a hydraulic fracturing operation from the arrival of the substances on the site to the end of well clean up when production starts. It does not cover the use of chemicals in exploration and production activities other than high-volume hydraulic fracturing nor site preparation and well abandonment. It is assumed that all of these activities are likely to take place at an onshore exploration and production site which will be developed according to stringent standards in order to minimize emissions to air, water and soil (European Commission, 2014). Transport is not considered under REACH and is dealt with through other regulatory regimes.
3) This report covers emission characterization during aboveground and subsurface activities. However, subsurface processes during correctly conducted hydraulic fracturing operations will not result in any emissions to relevant human or environmental receptors. This is supported by evidence presented in section 3.5 (Subsurface fracturing).
4) The emissions characterization in this report is based on available information on hydraulic fracturing operations. Emissions characterization is based on European well data High-volume hydraulic fracturing is less developed in the EU than in the US so emissions characterization has been supplemented with US data where necessary.

3. Main phases of a hydraulic fracturing operation

After being sourced to a site and stored, water is blended with hydraulic fracturing fluid products and proppant; this mixture is hereafter referred to as the fracturing fluid. The fracturing fluid is then injected into the well to fracture the formation.

The composition of the fracturing fluid and the pumping regime depends on the well design and the properties of the reservoir being fractured.

The injection stage of the fracturing process takes place over a relatively short period of time (typically from around one hour to several hours) but treatment may occur in stages over a number of weeks and be repeated if reservoir productivity declines.

During the hydraulic fracturing operation, some formation water and leached minerals, as well as hydrocarbons from the formation are mixed with the fracturing fluid. A review of the open literature by JRC [4] found that typically 20% to 50% (with an anticipated maximum of 75%) of the initially injected fracturing fluid is reported to be recovered during well flowback.

The recovered fluid is then managed in accordance with the EU Mining Waste Directive[3] (which includes the requirement for a waste management plan setting out methods for re-use and disposal) and local legislation and conditions. Management options considered here include treatment and re-use, management by a regulated waste facility and subsurface injection into a disposal well.

There are a number of possible fates for the injected fracturing fluid. Some components will be consumed in the process, e.g. hydrochloric acid reacting with formation rock, or corrosion inhibitors adhering to the metal surface of the casing and protecting it from corrosion. Some of the fracturing fluid will mix with formation water and then either return to surface as recovered fluid (i.e. produced and flowback) (20–75%) or remain in the formation (80–25%).

The fracturing fluid that is not produced back remains in the reservoir into which it has been injected (unless, of course, if there is a pathway to another formation).

Fracturing fluid is unable to migrate beyond the formation into which it was injected as the reservoir is covered by impermeable and sealing layers, which prevented fluid migration out of the reservoir. These sealing layers are much more difficult to fracture than the reservoir rock and the hydraulic fracturing operations are designed to prevent fracturing through these layers and opening new pathways. Any abnormal pressure is detected during fracturing operation and operation is immediately stopped.

New pathways would raise potential environmental concerns and could additionally lead to production losses due to gas migration out of the reservoir. In order for

[3] Directive 2006/21/EC on the management of waste from the extractive industries (the mining waste directive) [5].

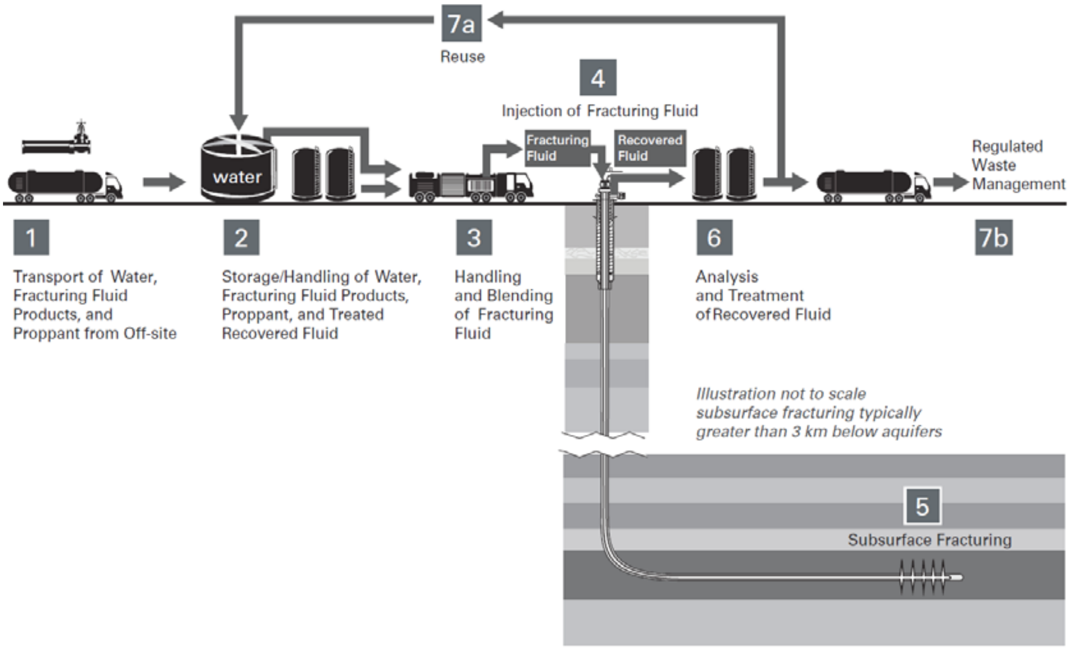
migration to occur there would have to be a pathway and enough pressure for the fluids in the well to free-flow, i.e. move without assistance. Free flow potential is an important factor to consider in the design of the fracturing operation and is considered as part of the overall well assessment.

Whilst the site remains in operation, the fracturing fluid continues to perform a useful purpose. After the well has completed its production life, and the well is abandoned, the 80–25% of the fracturing fluid that does not return to the surface and remains in the formation is treated as a mining waste. It is subject to the Mining Waste Directive and is managed in accordance with the site's waste management plan.

By way of example in England, the Environment Agency (EA) will not accept the surrender of the site's permit without being satisfied that the operator has taken necessary measures to avoid any pollution risk resulting from the operation of the regulated facility and to return the site to a satisfactory state.

Generally, it must be shown that any waste left on site is in accordance with the waste management plan and that it presents no risk to the environment. This report does not include consideration of issues relating to site preparation or well abandonment. As such, the retained fluid will not be considered further in this report or SpERC.

The main phases are explained in 3.1 to 3.7.



Source: Halliburton

Figure 1: General flow chart of the hydraulic fracturing cycle

3.1 Transport of water, fracturing fluid products and proppant from off-site

Water is transported to the site, e.g. by trucks or pipelines. Fracturing fluid products and proppant are transported to the site, e.g. by trucks or trains. All transport is carried out in accordance with local regulations and conditions. Transport is not considered under REACH therefore emissions during transport will not be considered in the next sections.

3.2 Storage/handling of water, fracturing fluid products, proppant and treated recovered fluid

Water is stored on the site using different methods, depending on local regulatory requirements. Storage methods include lined pits and closed tanks. These methods are shown in Figure 2.

Source: ConocoPhillips *Source: Chevron*

Figure 2: Different types of water storage (lined pits and 400 bbl storage tanks)

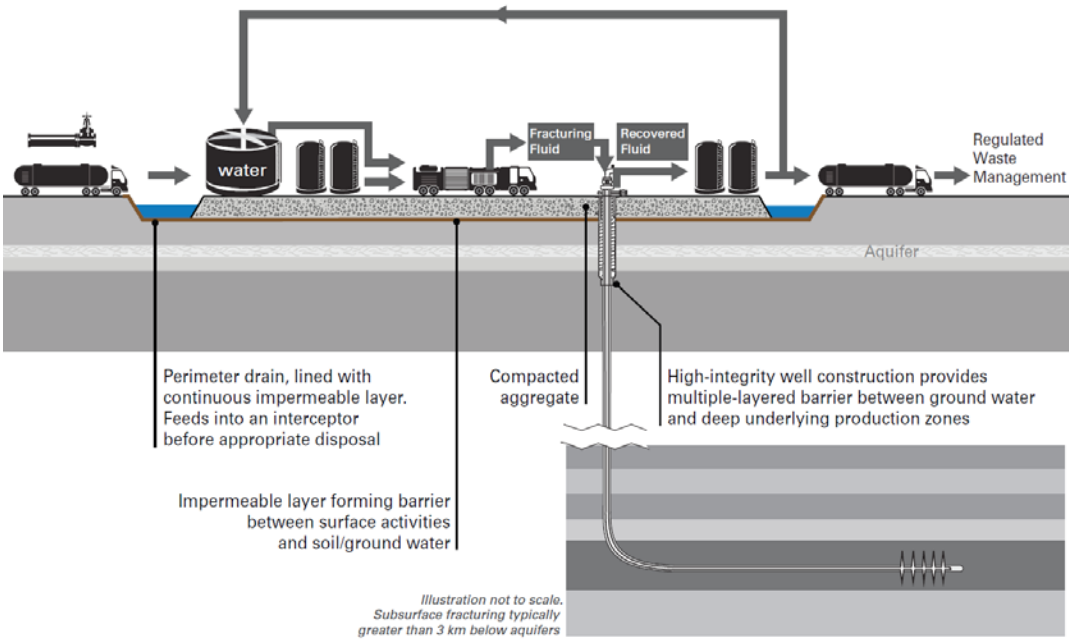
Proppant (e.g. sand, proppant may be coated or uncoated) and fracturing fluid products are transported to the installation by truck and stored on site in tanks and containers in accordance with EU and local regulations and conditions. Detailed information on fracturing fluid is in section 4 (Use of fracturing fluid products in hydraulic fracturing).

3.2.1 Containment of aboveground activities

A high-volume hydraulic fracturing installation must be designed and constructed in such a way as to prevent the downward migration of fracturing fluid products that may be released through leaks or spills. For example, this can involve the removal of an upper layer of soil from the site and the excavation of a ditch around the perimeter.

This is followed by the installation of a non-permeable membrane, which lines the entire area, including the intercepting ditches. The membrane is then covered in surfacing material such as aggregate (Figure 3).

In the unlikely event that surface water at the installation is contaminated with fracturing fluid products, it will be held in the ditches, rather than draining to the surrounding environment. Water thus contained will be removed for disposal according to EU and local regulations and conditions. The membrane under the installation (or similar means of secondary containment) prevents flow downwards to soil and groundwater.



Source: Halliburton

Figure 3: Typical design of a hydraulic fracturing installation

Figure 4 shows a typical installation with rectangular storage tanks, a vertical sand tower and smaller fracturing fluid product containers. Good practice for secondary containment of stored liquids includes the use of individually lined and bunded areas as well as the continuous liner underneath the prepared work area.

Source: Chevron

Figure 4: Hydraulic fracturing installation showing storage tanks, bunded fracturing fluid product containers and a vertical sand tower

3.3 Handling and blending of fracturing fluid

The three ingredients of fracturing fluid are mixed in two steps:

1) Water and fracturing fluid products are transferred in separate pipes to a pump where they are mixed.
2) The mixture of water and fracturing fluid products is piped to the blender where it is mixed (at low pressure) with sand or proppant to form slurries.

3.4 Injection of fracturing fluid

Low pressure slurries are fed to high pressure pumps and then injected into the formation via the wellhead. The mixing and pumping processes are summarized in Figure 5.

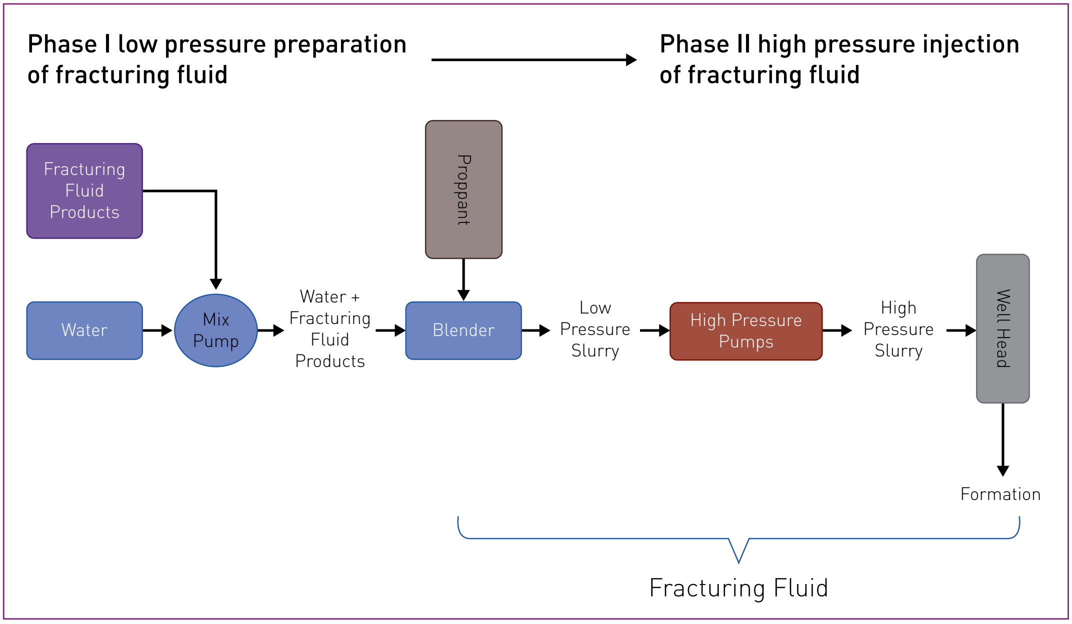


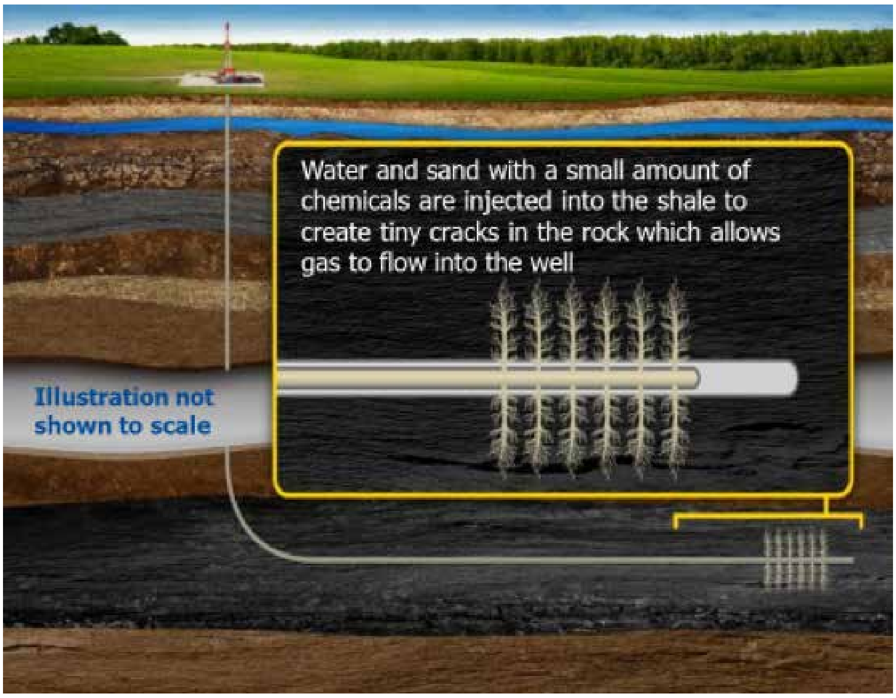
Figure 5: Preparation and injection of the fracturing fluid into the formation

3.5 Subsurface fracturing

Hydraulic fracturing is used to release hydrocarbons that are trapped in impermeable rocks. The fracturing fluid exerts pressure against the rock, creating a network of tiny fractures in the formation that are held open by the proppant allowing the hydrocarbons to flow from the targeted formation to the well (Figure 6).

Hydraulic fracturing fluid typically comprises 90% water, 9.5% proppants and 0.5% fracturing fluid products [6, 7]. These are average values for US operations and may be higher in other regions. e.g. 2.5% fracturing fluid products in Poland. The values from Poland are based on 23 exploration wells at 19 sites. See Appendix A, European exploration wells data.

The precise makeup of a fracturing fluid used in a particular well will depend upon the type of fluid pumped, the stage of field development and the formation being fractured. See section 4 (Use of fracturing fluid products in hydraulic fracturing).



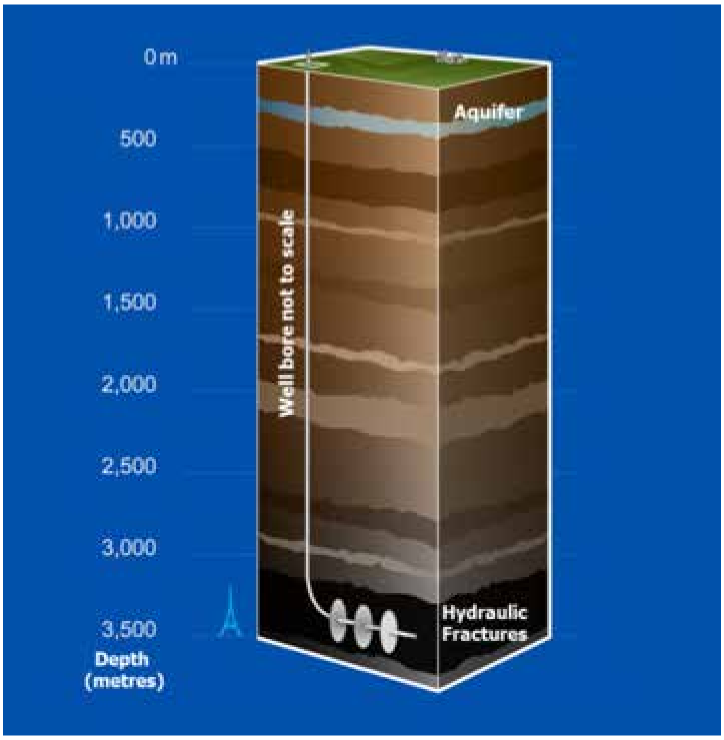
Source: Chevron

Figure 6: Hydraulic fracturing from a horizontal well

3.5.1 Fracture growth and containment

The risk of exposures from hydraulic fracturing operations must first be considered on an appropriate scale (Figure 7). Hydrocarbon formations are typically separated from shallow water aquifers by at least 600 m.[4] This is formation specific and there is often 2,000 – 3,000 m of rock separating the formation from the shallow water aquifers.

[4] Cuadrilla's response at EV83 stated that "shallow water aquifers – including shallow water aquifers at Cuadrilla's exploration sites in Lancashire – tend to be located at depths no greater than 1,000 feet below the surface, whereas the shale geological formations where fracking takes places tend to be located at depths of at least 5,000 feet below the surface". (One metre is roughly equivalent to 3.28 feet.) [8]



Source: Chevron

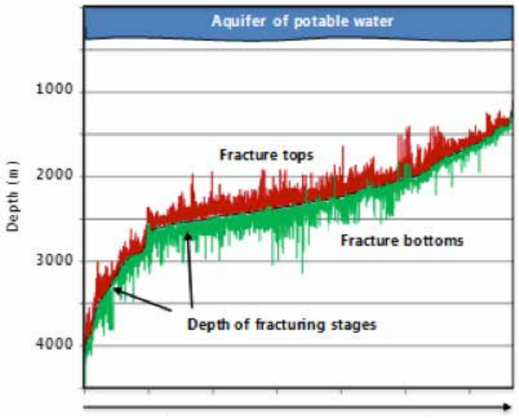
Figure 7: Distance from surface to the target formation and hydraulic fracturing activities

The results of more than 10,000 fracturing operations[5] have demonstrated that the vertical propagation of the fractures is well-contained. The measured height growth is often less than conventional hydraulic fracture propagation models predict because of a number of containment mechanisms (including complex geological layering, changing material properties and formation of hydraulic fracture networks) [9, 10].

Given the volume of fluid that is injected during hydraulic fracturing and the pumping power used, in 80% of cases the vertical extent is <250 m. In exceptional circumstances there is a ~1% chance of >350 m propagation above the target formation [10].

[5] Fracturing a well normally involves pumping multiple batches of fluid. Each discrete operation or batch of fluid is typically referred to as a stage.

According to Davies et al. [10] the maximum height of a stimulated high-volume hydraulic fracture is approximately 588 m (see Figure 8), which occurred in the Barnett shale, USA. This figure was derived using microseismic data which are thought to provide a conservative estimate as the seismic activity may be recorded as occurring well above the actual fracture.



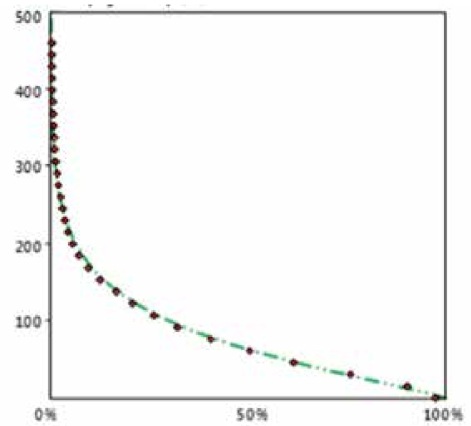
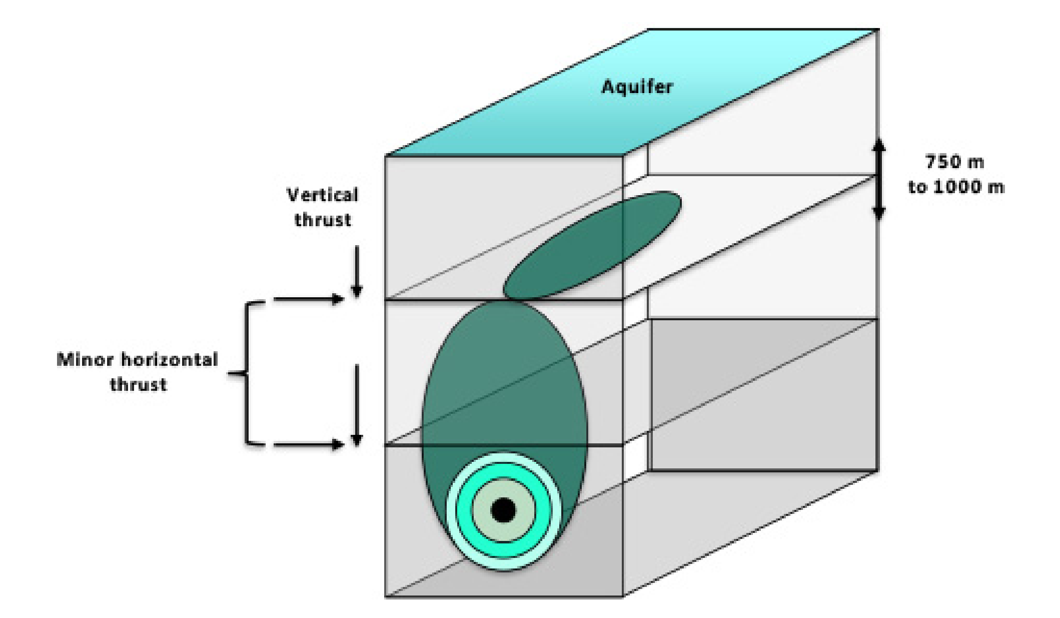


Figure 8: Distance from surface to the formation and probability of upward fracture height growth [9]

Fracture direction also varies with depth and the relative rock stresses (Figure 9). Stimulated fractures will propagate vertically as long as the minor horizontal thrust is weaker than the vertical thrust [11]. However, at ~600 to ~1,000 m depth, the vertical thrust becomes lower than the minor horizontal thrust and the fracture turns and propagates horizontally [12].

The removal of groundwater and hydrocarbons from the well reducing the pressure near the wellbore will cause fluids to flow in that direction (i.e. towards the wellbore or towards lower pressure in accordance with Darcy's Law). Therefore, any remaining fluids would be drawn to the wellbore and are not likely to migrate away. This means that upward fluid flow would not be expected even if the presence of multiple layers of very low permeability rock did not effectively prevent it.



Source: Total

Figure 9: Diagram showing the variation of fracture direction with depth

An integral part of the drilling and well construction process is the geological evaluation of the formation and overlying rock together with the identification and evaluation of geological faults and risks. This gives confidence that any induced or naturally occurring fractures do not, and/or will not, propagate beyond the barrier layers, and that there is no cause for concern with regard to the upward transport of fluids (such as shale gas, formation water and fracturing fluid).

The rocks above the target formation generally include several relatively impermeable layers (barrier layers). This is the mechanism that keeps oil and gas as well as other formation liquids in the target formation over geological time scales. Such formations restrict upward fluid movement. Hydrocarbons are less dense than water and would more readily escape through migration paths if these existed.

The presence of relatively impermeable formations above the target formation would limit upward fluid migration, unless fractures are not well controlled and extend beyond the target formation into the relatively impermeable rock layers above. However, as explained above, measures are taken to ensure that fractures do not propagate beyond barrier layers. Even in cases where fractures do propagate beyond the target formation, often multiple relatively impermeable rock layers separate the target formation from shallow water aquifers and the physical distances involved minimize any risk.

Proper design and continuous control of fracture propagation is therefore crucial to avoid groundwater contamination in the long term [13]. Operators and service companies take this into account when designing fracturing operations. Current evidence[6] relating to European shale gas wells indicates that between 1,000 and 3,000 m typically separates the tops of the fractures and sources of drinking water thus it is unlikely that hydraulic fractures will propagate from the formation to groundwater aquifers. This has never been known to occur and is highly unlikely if not implausible particularly given the tendency for the fractures to propagate horizontally rather than vertically at shallower depths (Figure 9).

In light of these factors, contamination of groundwater caused by the hydraulic fracturing technique is highly unlikely and there are no substituted cases of groundwater pollution that are associated with the propagation of high-volume hydraulic fractures[7].

As onshore exploration and development of hydrocarbons (including shale gas) develops in the EU, deeper wells may be drilled potentially increasing the physical separation between fractures and sources of drinking water. In future, the drilling of shallower wells with less physical separation may also be justified by scientific evidence and geological data demonstrating that upwards propagation of stimulated high-volume hydraulic fractures can be sufficiently controlled.

Recently, the EPA draft report of the Assessment of the Potential Impacts of Hydraulic Fracturing for Oil and Gas on Drinking Water Resources in the USA [18], where the average depth of wells is shallower then in the EU, concluded that there are above and below ground mechanisms by which hydraulic fracturing activities have the potential to impact drinking water resources. However, the EPA did not find evidence that these mechanisms have led to widespread, systemic impacts on drinking water resources in the United States.

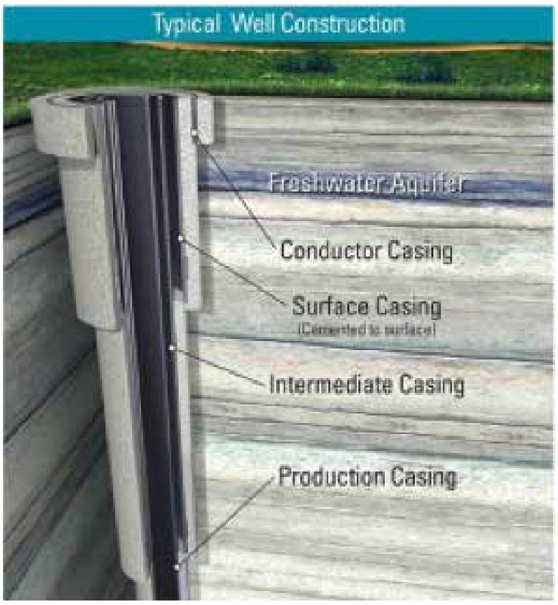
[6] House of Commons Energy and Climate Change Committee, Shale gas: Fifth Report of Session 2010-2012, May 2011. Cuadrilla's response at EV83 stated that "shallow water aquifers-including shallow water aquifers at Cuadrilla's exploration sites in Lancashire – tend to be located at depths no greater than 1,000 feet below the surface, whereas the shale geological formations where fracking takes place tend to be located at depths of at least 5,000 feet below the surface" where (1m is roughly equivalent to 3.28 feet) [8].

[7] An analysis undertaken by the consulting firm ICF International for the New York State Department of Environmental Conservation (NYSDEC) concluded in 2009 after extensive study that hydraulic fracturing of shales does not pose any risk to drinking water supplies associated with the fluids pumped into the target formation during the hydraulic fracturing process. In reaching this conclusion, NYSDEC relied in part on the statements of regulatory officials from 15 states – including Colorado, New Mexico, Pennsylvania, Ohio, Texas and Wyoming – that hydraulic fracturing operations have not led to groundwater contamination [14]. The US Environmental Protection Agency stated that "in no case have we made a definitive determination that the fracking process has caused chemicals to enter groundwater [15]. Similarly, the Interstate Oil and Gas Compact Commission's 2002 members' survey found that nearly one million wells had been hydraulically fractured over the course of several decades but found no evidence of substantiated claims of drinking water contamination due to hydraulic fracturing [16]. This remains the position to date with research showing over 2 million wells have been hydraulically fractured [17].

3.5.2 Wellbore Integrity: Design and construction

Wellbore integrity is fundamental to the protection of groundwater. A wellbore is not just a tube that carries hydrocarbons to the surface – it is also an environmental barrier that protects the surface and aquifers during gas and oil exploration (including hydraulic fracturing).

Fracturing fluid, recovered fluid and hydrocarbons are kept separate from groundwater and the soil by multiple layers of impermeable cement and steel casing (Figure 10), which is tested to ensure wellbore integrity.



Source: Reprinted with permission from ConocoPhillips

Figure 10: Typical well construction of an abandoned wellbore

Isolation of hydrocarbons and pressure containment is the basis of wellbore design and construction which are specified by best practices and industry guidelines and are designed to keep formation fluids (and thus injected fracturing fluids) in place and prevent escape. See [19] to [21] for examples.

A correctly designed, constructed, maintained and subsequently abandoned wellbore as illustrated in Figure 11 will ensure that there is no pathway from the formation to potential receptors. This also provides isolation and protection to humans and the environment and will minimize any risks associated with fracturing fluid products that are pumped into or left in the formation.

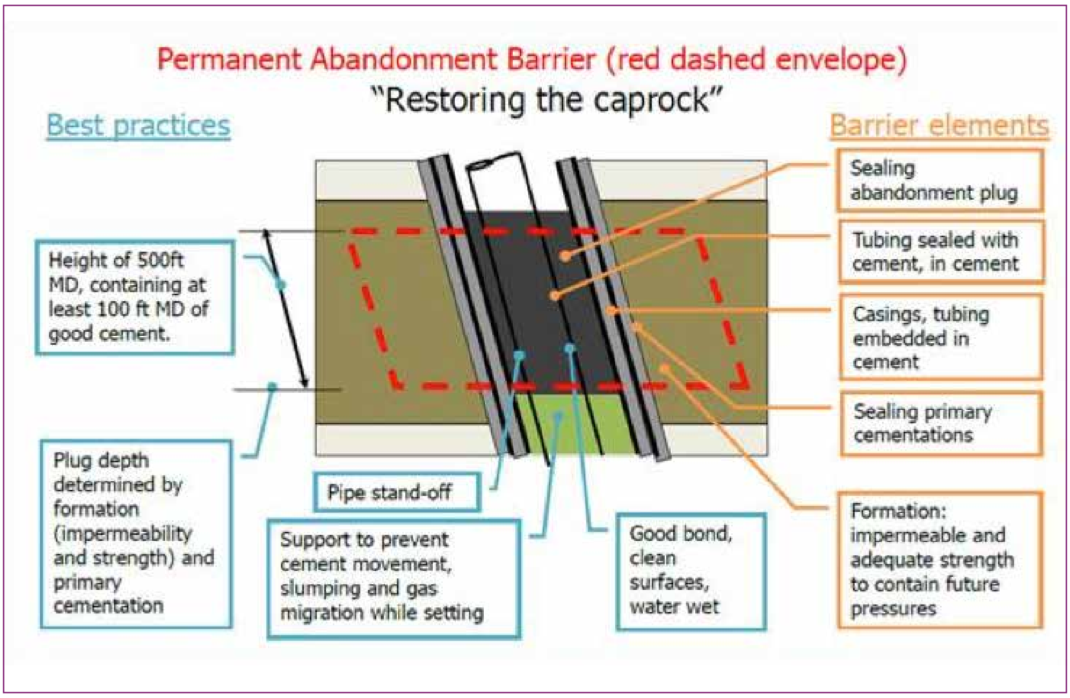


Figure 11: Schematic of a permanent abandonment barrier showing the barrier envelope (red dashed line) that restores the integrity of the cap rock, its barrier elements and recommended practices [20]

The importance of wellbore integrity is recognized by EU regulators and industry. Specific legislation, industry guidelines and good practice have developed which address wellbore integrity issues. Provided these are applied the risk to groundwater as a result of hydraulic fracturing is minimal.

As an example, development of wellbores that are separated from the environment and human receptors by a minimum of two independent technical barriers (double barrier principle) at all times has proved to be a highly effective method [22]. Well integrity monitoring and assurance plans are required as part of a successful permit application to carry out operations.

3.6 Analysis and treatment of recovered fluid

Once the fracturing fluid meets the targeted formation, it will typically mix with dissolved material from the formation that was in contact with the fracturing fluid, and formation water. As reviewed by JRC [4], typically 20% to 50% (with an anticipated maximum of 75%) of the initially injected fracturing fluid is reported to be recovered during flowback in the open literature. This initially injected fracturing fluid is mixed with some formation water and small amounts of minerals from the formation. For more information on the quality and quantity of recovered fluid, see 4.3.

Recovered fluid is managed in accordance with the EU Mining Waste Directive (which includes the requirement for a waste management plan setting out methods for re-use and disposal) and local legislation and conditions.

Best Available Techniques (BAT) for the on-site treatment of recovered fluid are being developed. Best management practices regarding recovered water are discussed in ERM's Recovered water management study in shale wells, June 2014 [23], and should consider an integrated water management plan that takes into consideration issues including recovered fluid (flowback and produced water) and how this fluid will be handled.

The EU and UK EA are currently in the process of engaging with industry on what represents Best Available Techniques (BAT) for the treatment of onshore oil and gas wastewaters. United Kingdom Onshore Operators Group (UKOOG) guidelines [24] explain that operators should have information regarding flowback fluids available for disclosure. This includes the proposed method of handling the recovered fluids, including but not limited to, tank requirements, pipeline requirements, flaring, flowback and storage periods, recycle and re-use and information on proposed disposal methods.

3.7 Reuse and waste management of recovered fluids

There are generally three management options for the recovered fluid. Fluid may be:

1) treated and reused for further hydraulic fracturing
2) injected into a disposal well
3) transported to a regulated waste management facility.

UKOOG guidelines [24] set out that operators should always dispose of fracturing fluid that is no longer required (or unable to be re-used) at an approved waste management facility in accordance with EA/Scottish Environment Protection Agency regulations. The UK's Department of Energy & Climate Change has produced guidance Fracking UK shale: water [25] which sets out that flowback fluid is categorized as mining waste, so the operator must obtain an environmental permit for its disposal from the relevant environmental regulator and have an agreed waste management plan in place.

The methods for disposal can be:

- on-site treatment with re-use of water and disposal of remaining liquids and solids to a suitable licensed waste treatment and disposal facility[8]
- removal off-site to a suitable licensed waste treatment and disposal facility
- disposal to a special sewer with the permission of the relevant waste water utility company.

IOGP Shale FAQs state that appropriate government authorities issue permits for handling and disposal of flowback/produced water. This procedure is consistent with the EU Mining Waste Directive.

Waste fluid produced as part of the hydraulic fracturing operation is included in the waste management plan (required under the Mining Waste Directive). In accordance with the waste hierarchy, local conditions and local regulatory requirements, as much of the flowback fluids as possible will be re-used in future fracturing operations.

Waste water that is unsuitable for re-use or where local conditions mean re-use is not practicable will be processed via licenced waste contractors. Providing consenting/permitting requirements are met, this waste could be discharged (after analysis and treatment) via waste water treatment works to surface waters. Alternatively, this water could be disposed of through re-injection into disposal wells in accordance with EU and national regulations.

[8] N.B: Injection wells are subject to the EU Mining Waste Directive and would be licensed as waste disposal facilities. It is covered also by the Water Framework Directive and in some cases also by the Industrial Emissions Directive.

4. Use of fracturing fluid products in hydraulic fracturing

The types of fracturing fluid products used in hydraulic fracturing operations can be grouped according to their function in the process (Table 1).

4.1 Composition of fracturing fluid

Fracturing fluid compositions vary according to the specific needs of each area and rock type. The composition of each fracturing fluid is designed to specifically address the individual characteristics of each site. Key considerations include the ductility or brittleness of the rock, the permeability of the formation, pump rates and the desired viscosity of the fluid.

Selection of fracturing fluid is more sophisticated than a simple choice between a relatively simple, high-volume, 'slickwater' fracturing fluid and more complex high viscosity systems containing multiple fracturing fluid products.

Examples of the different types of fracturing fluid are shown in Figure 12.

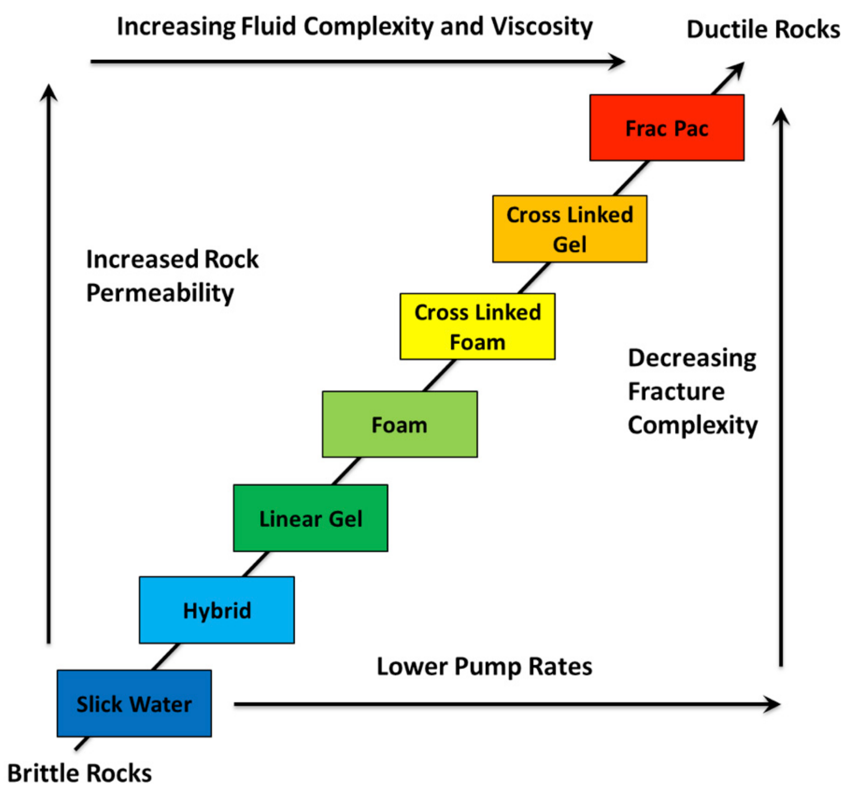
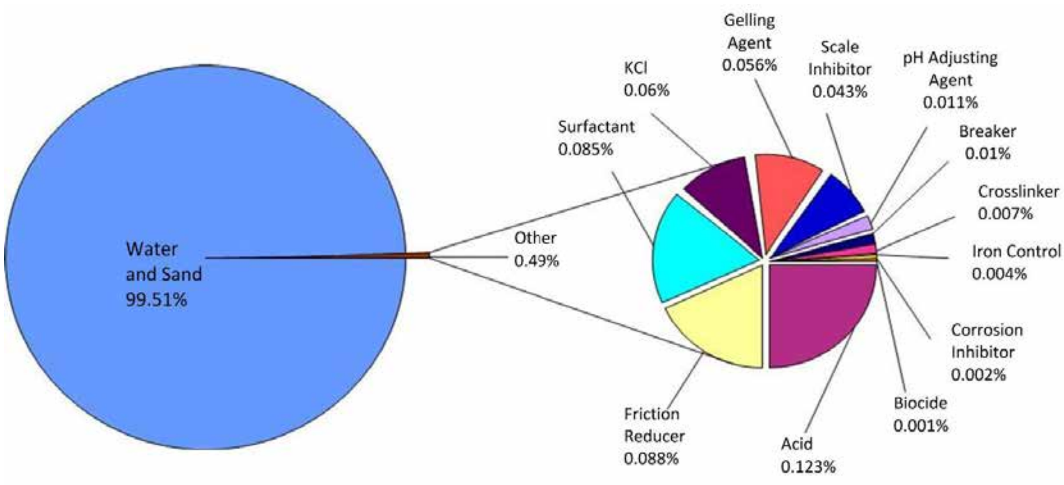


Figure 12: Variation of fracturing fluid with formation and desired fluid properties/ pump rate

The hydraulic fracturing industry has many different types of fracturing fluid products that can be used in a fracturing fluid. Any single hydraulic fracturing operation would only use a few of the available fracturing fluid products.

Table 1 lists 12 fracturing fluid products that cover a range of possible functions that could be built into a hydraulic fracturing fluid. It is not uncommon for some fracturing fluid designs to omit some categories of fracturing fluid products if the function served by a category of products is not required for the specific well design.



Source: ALL Consulting based on data from a fracture operation in the Fayetteville Shale, 2008, Modern Shale Gas Development in the United States: A Primer, U.S. Department of Energy [6].

Figure 13: Volumetric composition of a fracturing fluid

Table 1: Fracturing fluid products – examples of main constituent substances and function within a fracturing fluid

Type or function of fracturing fluid product	Example of main constituent substances	Purpose within fracturing fluid
Diluted acid (15%)	Hydrochloric acid, acetic or formic acid	Clean up of perforations in the casing. Helps dissolve minerals and initiate cracks in the rock
Biocide	Glutaraldehyde, quaternary ammonium chlorides	Eliminates bacteria in the water that produce corrosive by products
Breaker	Ammonium persulfate, magnesium peroxide	Allows a breakdown of the gel polymer chains for placement of the proppant (e.g. sand)
Corrosion Inhibitor	Propargyl alcohol, amines, aldehydes	Prevents the corrosion of the pipe
Crosslinker	Borate salts, zirconium complexes	Maintains fluid viscosity as temperature increases
Friction reducer	Polyacrylamides	Minimizes friction between the fluid and the pipe
Gelling agent	Guar gum or polysaccharide (i.e. derivatized cellulose)	Thickens the water in order to suspend the proppant
Iron control	Citric acid, Acetic acid, thioglycolic acid	Prevents precipitation of metal oxides
KCl (i.e. brine)	Potassium chloride	Clay stabilizer or a brine carrier fluid
pH adjusting agent/buffer	Sodium carbonate, potassium carbonate, sodium hydroxide, potassium hydroxide	Controls pH and maintains the effectiveness of other components, such as cross-linkers
Scale inhibitor	Phosphonates, acrylamide–acrylate copolymer	Prevents scale deposits in the pipe or the formation
Surfactant	Ethoxylated alcohols, glycol ether, methanol or isopropanol as a solvent	Reduces surface tension of the fracturing fluid in the formation and during fluid recovery

NOTE: Fracturing fluid formulation is site-specific and the actual main constituent substances and fracturing fluid composition may vary.

The fracturing fluid products shown in Table 1 are representative of the major product functions used in hydraulic fracturing of gas shales. Table 1 provides examples of the main constituent substances in each type of fracturing fluid product, and also the purpose for which the product is used in a fracturing fluid. Other product functions not reflected in the table can include clay control, sand consolidation, and oxygen scavenging.

4.2 Volume of fracturing fluid products used in fracturing fluid

Information on fracturing fluid products used for hydraulic fracturing in the EU is provided by operating companies on a voluntary basis in NGS Facts [2]. Further data are also available on the Polish Exploration and Production Industry Organization website [26].

This report considered information on 19 sites and 23 wells in Poland – see Appendix A (European exploration wells data). These data show that between 0.5 and 515 m^3 of fracturing fluid products (i.e. total fracturing fluid minus water and proppant) have been used for hydraulic fracturing.

Detailed analysis of the amount and potential environmental hazard of individual substances used in the hydraulic fracturing fluids shows that the substances used in the greatest amounts are not hazardous and therefore unlikely to require a quantitative safety assessment under REACH.

Substances that may be considered to be hazardous to the aquatic environment are used in lower concentrations. Petroleum distillates, which are classified as hazardous to the environment, were found to have been used on three occasions at a rate of 0.2% of the total fracturing fluid; however, a far more typical use rate of this product is less than 0.03% and the majority of other substances are used in concentrations well below this.

As a result of this analysis, 0.03% of total hydraulic fracturing fluid is the value taken to represent a typical use rate of fracturing fluid product. EU data from hydraulic fracturing sites (Appendix A) show that the mean volume of fracturing fluid (water, proppant and chemical) used is 6633 m^3.

A typical volume for a single substance used in fracturing fluid is therefore $0.03\% \times 6633\ m^3 = 2\ m^3$ or 2000 kg (assuming a relative density of 1.0).

As data from EU sites is limited, chemical use in US operations was also reviewed for comparison. Data from FracFocus has been thoroughly analysed and summarized by the US Environmental Protection Agency (EPA) [18]. This report showed that the estimated median volume of chemicals used, varied widely, covering a range of almost zero to 98,000 L. The mean of the estimated median volume of chemical use per site was 2,500 L. Although comparison of such diverse data from the US, with EU volumes, is of limited relevance, it does indicate that amount of 2000 kg[9] selected for the SpERC and generic exposure scenario is reasonable for representing a 'typical' tonnage of chemical used in hydraulic fracturing.

The average amount of proppant used per fracturing operation has been estimated to be 457 tonnes (based on EU exploration wells data). A review of Safety Data Sheets for coated proppant suggests that the typical amount of coating applied makes up 5% of the total mass. However, it should be noted that not all proppant is coated. Given that only a very limited number of wells have been hydraulically fractured in the EU, there has been no attempt to further subdivide this figure.

It is assumed that 5% is the amount for one individual component of the coated proppant, hence the amount of substance used in the coated proppant is 5% of 457 tonnes = 23 tonnes per fracture. As individual components may be used in lower concentrations, this is an over-estimate and results in a conservative safety assessment.

4.3 Recovered (produced and flowback) fluid quality

Recovered fluid quality (and quantity) is expected to vary significantly over time and with the type of formation involved in the oil and gas extraction. Recovered fluid will generally mirror the natural formation water (discussed below) with the addition of small amounts of the returned fracturing fluid (discussed earlier) including proppant (typically sand, proppant may be coated or uncoated) and some fine silt and clay particles from the formation and possibly some dissolved hydrocarbons (e.g. oil and/or natural gas).

Formation water naturally present and in contact with the rock in the target extraction zone contains:

- high levels of Total Dissolved Solids (TDS) which are brines (or salt solutions) such as calcium chloride, sulfate, etc.
- minerals that have leached out of the formation rock such as barium, calcium, iron, strontium, and magnesium and are present in various forms both dissolved and in solid (i.e. particulate) such as silt and clay
- bacteria
- Trace amounts of naturally occurring radioactive materials (NORM) from the formation rock such as radium, uranium, and lead.

[9] 2000 kg = 2000 L assuming a density of 1.0.

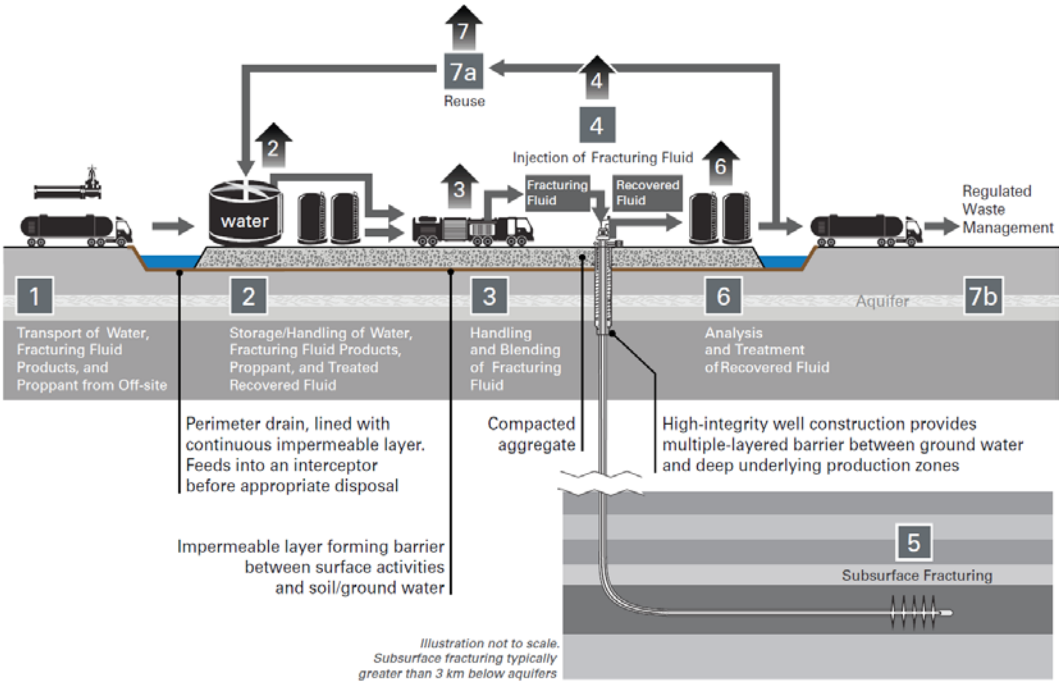
Dissolved hydrocarbons may also be present in the recovered fluid but this will depend on the nature of the formation and the target resource (oil or natural gas or a combination). Hydrocarbon constituents can include dissolved methane, ethane and propane consistent with the recovery of natural gas. They can also include benzene, toluene, ethyl benzene and xylene (BTEX) compounds consistent with the recovery of crude oil [27].

There are several options to manage hydrocarbons during the flowback phase and all liquids and gases are treated in accordance with local regulations. Options for small scale exploration and appraisal wells include flaring under controlled conditions, e.g. enclosed flares, or the use of green completions (which involve capturing gas at the wellhead rather than releasing it into the atmosphere or flaring. This results in environmental benefits from reduced emissions and economic benefits as the gas is captured for sale).

Development and production projects may use a combination of green completions and on-site power generation.

5. Emission characterization for the hydraulic fracturing operation

Emission characterization for hydraulic fracturing has been compiled by considering potential emissions that may take place at each phase of the whole fracturing process. These phases and corresponding activities are depicted in Figure 14.



Source: Halliburton

The numbers assigned to the phases correspond to numbering used in section 3 (Main phases of a hydraulic fracturing operation) and to 5.1 to 5.7.

Figure 14: Depiction of main sources of potential emissions to air, water and soil during a hydraulic fracturing operation

Emission factors are given as a percentage, which should be applied to the amount of (REACH registered) substance used in fracturing operations. In order to control and optimize the process, fracturing operations may be carried out in a number of stages. This exposure scenario provides a conservative assessment as it assumes a single stage high-volume hydraulic fracturing operation in which all of the fracturing products are pumped in a single batch.

Certain assumptions have been made when deriving estimations of emissions for the generic environmental exposure scenario:

- For activities taking place on the production site, best practice would ensure emissions to water and soil are prevented through the design of the installation. By way of example, secondary containment and impermeable liners to ensure that emissions to water and soil, from activities taking place above-ground would not be possible at dedicated high-volume hydraulic fracturing installations (see 3.2). Taking this into account, emissions to soil and water are set to zero.
- The discharge of waste water via a treatment plant may result in release of substance to surface water. This step has therefore been considered as a separate activity to those taking place at the production site.
- Separate emissions have been estimated for proppant[10] and fracturing fluid products.

In order to make the hydraulic fracturing exposure scenario generic, physico-chemical and fate properties of individual substances have not been considered. A conservative approach has been taken which results in estimated exposures that may be unrealistically high, but lead to a protective risk assessment for the environment.

5.1 Transport of proppant and fracturing fluid products from off-site

Transport of substance is not considered under the REACH regulation. Losses during transport are assumed to occur through accidents only. Therefore it is assumed that no relevant environmental emissions take place in this phase of the operation.

- *Emission factor for transport: 0% to air.*

5.2 Storage and handling of fracturing fluid products, proppant and treated recovered fluid

For this phase, handling is described as transfer of product from one piece of equipment to another, e.g. transfer of product from tanker to storage containers.

[10] Proppant frequently consists of crystalline silica, quartz (i.e. sand) or ceramic and is therefore non-hazardous to the environment, i.e. it would not normally require an environmental exposure scenario. However, some proppants are enhanced with coatings to improve their physical properties. Such coatings may contain substances for which an exposure scenario may be required. For this reason, loss of coated proppant to the environment has been considered.

The chemical substances that are constituents of hydraulic fracturing fluid are referred to as fracturing fluid products (shortened to 'product') in order to distinguish them from water and proppant.

5.2.1 Fracturing fluid product

Storage-product

The highest losses during storage are expected to be from volatile products, and therefore this case was taken as a worst case assumption. The EA document on industrial emissions [28] gives the example of gasoline for the storage of volatiles, with the following emission factor:

- *Gasoline 1.14 kg VOC/m^3 storage capacity / year ~ equivalent to 0.1% [29]*

Storage of liquids in other vessels such as drums, or bulk containers is not expected to lead to significant losses to the environment.

- *Emission factor for storage of fracturing fluid products: 0.1% to air.*

Transfer-product

In a dedicated high-volume hydraulic fracturing installation, fracturing fluid products will arrive in bulk and be stored in local dedicated storage, or arrive in containers. Used containers will be removed and managed by suppliers. It is assumed that no intentional emissions will take place at this stage.

The EA report on industrial emissions [28] states the following values for transfer of liquids:

Splash unloading volatiles 2.0 kg VOC/tonne ~ equivalent to 0.2% to air

Submerged loading 0.8 kg VOC/tonne ~ equivalent to 0.08% to air.

As the method of transferring products may vary, the worst case emission factor has been assumed for this activity; i.e. a factor of 0.2%.

- *Emission factor for transfer of fracturing fluid products: 0.2% to air*
- **Total emission factor for storage and handling of fracturing fluid product is 0.3% to air.**

5.2.2 Proppant

Storage-proppant

Emissions from the bulk storage and transfer of toxic and/or reactive solids are generally negligibly small [28] as they are usually handled in closed systems or are stored in packaged form rather than loose material [30].

From the figures that are available [29]:

Minerals (e.g. chemical or fertilizer) in open storage piles: 20 kg/tonne, equivalent to 2%

Crushed materials (e.g. lime) in silos: 0.2 kg/tonne, equivalent to 0.02%.

As proppant will be stored in silos and not as open piles, the smaller emission factor will be applied.

- *Emission factor for storage of proppants: 0.02% to air*

Transfer-proppant

The EA document states that for emptying a tanker and in the absence of any other data, a figure of 1 mg/m^3 is assumed for solids with a low dust generation potential (for example, with a particle size of > 40 μm) and a figure of 10 mg/m^3 is assumed for solids with a high dust generation potential. The EA report also gives a figure for cement of 0.1 kg/tonne, equivalent to 0.01% [29].

- *Emission factor of proppants for transfer for this phase: 0.01% to air*
- **Total emission factor for transfer and storage of proppants: 0.03% to air.**

5.2.3 Treated recovered fluid

Where possible, recovered fluids are treated via a number of processes to remove metals, suspended solids, oil and salts [23]. The fluid is then used to prepare further fracturing fluid for injection.

The amount of fracturing fluid product remaining in the treated recovered fluid will be lower than that used to prepare fresh fluid. However, as this amount is varied and unknown, it has been assumed that all product is returned for re-use. It has also been assumed that recovered fluid is only reused for one further fracture.

Based on the above assumptions, the emission factor for this phase is equal to storage and handling of fracturing fluid product in 5.2.1.

- **Total emission for storage and handling of treated recovered fluid is 0.3% to air.**

5.3 Handling and blending of fracturing fluid

The following activities have been considered in this phase: transfer of product and periodic cleaning of equipment.

5.3.1 Fracturing fluid product

Transfer-product

Emissions during this activity are assumed to be the same as for transfer of product as described in 5.2.1.

- *Emission for handling of fracturing fluid product in this phase: 0.2% to air.*

Equipment cleaning – product

The amount of fracturing fluid product remaining in equipment after use has been taken to be equivalent to the estimated fraction of fluid remaining in a tanker before cleaning, provided in the EA report [28]. For a viscous fluid this is 1%. Although a viscous fluid will have low volatility, in order to present a worst case, it has been assumed that the whole of this fraction will be lost to air.

- *Emission of fracturing fluid product for cleaning equipment: 1%*
- **Total emission for handling and blending of fracturing fluid product: 1.2% to air.**

5.3.2 Proppant

Transfer proppant

Emissions during this activity are assumed to be the same as transfer of proppant as described in 5.2.2.

- *Emission for handling of proppant in this phase: 0.01% to air.*

Equipment cleaning – proppant

The amount of proppant remaining in equipment after use has been taken to be equivalent to the estimated fraction of a fine powder remaining in a tanker before cleaning, provided in the EA report [28]. This is 0.01% and, although proppant is not a fine powder and not completely volatile, it has been assumed that all of this residual fraction will be lost to air.

- *Emission of proppant for cleaning equipment: 0.01% to air*
- **Total emission for handling and blending of proppant: 0.02% to air.**

5.4 Injection of fracturing fluid

The injection process is a closed system that facilitates the hydraulic fracturing operation by pressuring the fluids in the well. If the system was not closed the required pressures would not be achieved. Once the fracturing fluid has been delivered to the formation via the well, a percentage of the fracturing fluid will be retained in the formation.

As reviewed by JRC [4], 20–50% (with an anticipated maximum of 75%) of the initially injected fracturing fluid is reported to be recovered during well flowback in the open literature. However, there are no emissions to relevant human or environmental receptors from subsurface injection of hydraulic fracturing fluids (see 3.4). Best practice in well installation and management will ensure that wellbore integrity is maintained and there is no loss of fracturing fluid.

- *Emission of fracturing fluid products and proppant for this phase: 0% to all compartments.*

5.5 Subsurface fracturing

During this phase, it is assumed that there are no emissions to relevant human or environmental receptors. (For justification, see 3.5.)

- *Emission of fracturing fluid products and proppant for this phase: 0% to all compartments.*

5.6 Analysis and treatment of recovered fluids

Activities considered for this phase are the treatment of volatile components of recovered fluids by flaring and transfer and storage of fluids. Sampling for analysis is assumed to result in negligible emission.

5.6.1 Fracturing fluid product

The recovered fluids will comprise a proportion of the fracturing fluid that is not retained in the formation and formation water and other substances naturally present. As previously stated, the volume of recovered fluids is expected to be 20–50% (with an anticipated maximum of 75%) of the initially injected fracturing fluid. Many of the fracturing fluid products are likely to be consumed or remain subsurface, however to provide a conservative assessment the exposure scenario will assess the fracturing fluid products as if 75% return to the surface.

Flaring

Recovered fluids will be treated to remove gas and this gas will either be flared on-site or collected for processing and consumption, the intrinsic value of the gas mandating the use of green completions wherever possible. Flare stacks should operate at >98% combustion efficiency and it is assumed that any volatile components that are likely to be in the gas phase will be incinerated during the flaring process along with the produced gas with the same efficiency. If we consider that 75% of products return to the surface and are all volatile and are all flared with 98% efficiency, emissions should be 0.75 × 0.02 = 1.5%

- *Emission of fracturing fluid product through flaring: 1.5%*

Transfer and storage – product

Emissions during this activity are assumed to be the same as in 5.2.1.

- *Emission of fracturing fluid product for handling and storage in this phase: 0.3% to air*
- **Total Emission factor for this phase: 1.8% to air.**

5.6.2 Proppant

Proppant is intended to remain at the formation; however, assuming some proppant does return with recovered fluid, it will not be in a form (i.e. dry) that can be lost to air.

- *Emission of proppant for analysis and treatment of recovered fluid: 0%.*

5.7 Reuse and regulated waste management

Management of recovered fluid is not considered in detail as there are regulations in place (e.g. the Mining Waste Directive, which includes the requirement for an agreed waste management plan setting out methods for re-use and disposal as well as local legislation and conditions) prescribing waste handling in hydraulic fracturing operations.

In accordance with the waste hierarchy, local conditions and local regulatory requirements ensure as much of the flowback fluid as possible will be re-used in future fracturing operations. Waste water that is unsuitable for re-use or where local conditions mean re-use is not possible will be processed via licenced waste contractors.

Providing consenting/permitting requirements are met and, after analysis and treatment, ultimately this waste could be discharged via a waste water treatment works to surface waters. Alternatively, this waste could be disposed of through re-injection into a disposal well where national regulations permit this.

For completeness and, as explained in section 3 (Description of the hydraulic fracturing operation), after the well has completed its production life and it is abandoned, the 25–80% of the fracturing fluid and proppant that does not return to the surface and remains in the formation is treated as a mining waste. It is regulated through the Mining Waste Directive and must be dealt with in accordance with the site's waste management plan.

By way of example in England, the EA will not accept the surrender of the sites permit without being satisfied that the operator has taken necessary measures to avoid any pollution risk resulting from the operation of the regulated facility and to return the site to a satisfactory state. Generally, it must be shown that any waste left on site is in accordance with the waste management plan and that it presents no risk to the environment. This report does not include consideration of issues relating to site preparation or well abandonment. As such the retained fluid is not considered further in this background document or SpERC.

As explained above there are no emissions from the injection of fracturing fluid or from subsurface fracturing. Physical and geological factors minimize the likelihood of any fluid migrating beyond the formation (see section 3).

5.7.a Re-use (on-site)

Re-use of recovered fluid on site in further hydraulic fracturing operations is the preferred method of management [23]. Emissions from re-use of treated recovered fluid have been addressed in 5.2.3. Note that only one cycle of fluid re-use has been considered for the derivation of emission factors in this phase.

- *Total emission of re-used treated recovered fluid is 0.3% to air.*

5.7.b Disposal (off-site)

Recovered fluids are stored and disposed of according to national and local regulations by regulated waste contractors. This may include discharge via a waste water treatment.

Proppant should be easily removed from returned water, therefore it is not expected to be present in the waste water sent to treatment plants. There is potential for other hydraulic fracturing products to be present, a small proportion of which may be discharged to surface water via this route.

The amount of substance released in the final effluent will depend on:

- the amount of substance used for fracturing and therefore assumed to be present in the returned water:
  - The amount of substance present in the returned water is assumed to be 75% (i.e. equivalent to maximum volume of returned water) of the amount used in the fracturing fluid. As described in 4.2, this would be 75% of 2000 kg = 1500 kg hydraulic fracturing product.
- the volume of returned water sent for treatment per day:
  - The volume of returned water sent for treatment is dependent on the rate at which the operator allows the well to flow and the volume that can be accepted by the treatment plant without compromising the efficacy of the plant.

    Most operators use a system of chokes to limit the initial pressure drawdown on the completion. This prevents damage to the fracture system and controls the maximum flow rate. Well mechanics and tubing size, production handling equipment capacity, water hauling/disposal capacity, etc. also play a role in the initial flow back rate. Typical rates for the initial flowback of hydraulically fractured horizontal shale wells are 50 to 100 bbls/hour range (191 to 382 m^3/day). These limits are followed regardless of the volume of water pumped into the well.

    Discussion with UK treatment providers that have had experience of treating fracturing fluid, revealed that a treatment works accepting returned water would need to be of a size that is capable of treating 100,000 population equivalents (20,000 m^3 flow per day). Note that this is 10 times larger than the default size of 10,000 population equivalents /2000 m^3 per day [31] usually used in risk assessment models.

    A volume of 382 m^3 waste water delivered from a fracturing site would therefore represent <1% of total waste water treatment plant influent, which therefore ensures good dilution with regular effluent.

    Based on the above, the volume of returned water to be treated per day has been taken to be 382 m^3.

- the removal efficiency of the treatment plant, which is dependent on the properties of the substance such as biodegradability and adsorption to particulates:
  - The removal efficiency of the treatment plant cannot be provided here as it is dependent on substance properties. Based on experience gained by chemical manufacturers through conducting chemical safety assessments for REACH, it is expected that 50–99% of substance will be removed prior to discharge.

Unintended releases to air during the transfer of the fluids from well to storage and from storage to transport equipment (e.g. containers) may also occur. These will be the same as during transfer and storage as described in 5.2.

Emission of product to air during the treatment stage will be estimated by a suitable model as part of the exposure assessment for REACH registration and is therefore not considered for the GES.

- Emission factor for disposal of recovered fracturing fluid products:
  - *75% to water prior to treatment at a waste water treatment plant* *0.3% to air* ***prior to treatment at a waste water treatment plant.***

5.7.c Injection

In some circumstances, recovered fluids may be re-injected into a well which is used for disposal. Such disposal wells are subject to EU and national regulations. As per the primary injection process, there are no emissions of the fracturing fluid products to relevant human or environmental receptors via this route.

6. Summary of emissions

Emissions described in section 5 are summarized in Tables 2a) and 2b).

6.1 Emissions to air

Emissions to air are for the installation, as emissions at a waste treatment plant will be estimated by an appropriate model as part of an exposure assessment.

Emissions to air for each phase on site have been added together to produce a total emission factor. This total emission factor is applicable to each fracturing treatment which we have assumed to take place over four days for fluid products (one day each for stages 5.2, 5.3 , 5.6 and 5.7) and two days for proppant (stages 5.2 and 5.3).

Fewer days are allowed for proppant as it is assumed there are no emissions to air from coatings during the water recovery stages. These are the worst case (shortest duration) scenarios.

Total emissions have been divided by 4 or 2, as appropriate, to give average emissions per day. For the generic exposure scenario, daily emission factors should be applied to the tonnage of chemical substance used in hydraulic fracturing products or coated proppant.

6.2 Emissions to water

Direct releases to water from activities taking place on the installation are set to zero due to the containment measures described in this report.

Emission to surface water may occur where recovered water is treated via a waste water treatment plant.

The number of emission days for treatment via a waste water treatment works has been calculated using generic values as follows:

Volume of fracturing fluid (6633 m^3) × fraction returned (0.75) / daily volume of returned water (382 m^3) = 13 days.

Therefore, the estimated emission factor to water is 75/13 = 5.8% per day **prior to treatment.**

For the generic exposure scenario, this daily emission factor should be applied to the tonnage of chemical substance used in hydraulic fracturing products.

6.3 Emissions to soil

Direct releases to soil from activities taking place on the production site are set to zero due to the containment measures described in this report.

Indirect emissions to soil (e.g. through deposition from air) will be estimated by an exposure model as part of the safety assessment.

Table 2a) Summary of estimated emissions to air at each phase of hydraulic fracturing

Operation	**Relevant section of report**	**Estimated Emissions (%)**			
		Fracturing fluid product			**Proppant**
Transport	5.1	0			0
Storage and handling	5.2	0.3			0.03
Handling and blending	5.3	1.2			0.02
Injection of fluid	5.4	0			0
Subsurface fracturing	5.5	0			0
Treatment of recovered fluid	5.6	1.8			0
Waste:					
re-use (on-site)	5.2 & 5.7a	0.3			0
disposal (off-site)	5.7 b		0.3		0
injection	5.7 c			0	0
Total emissions per fracturing operation		3.6*	3.6	3.3	0.05
Average emissions to air per day		**0.9**	**0.9**	**0.825**	**0.025**

** Although re-use of recovered fracturing fluid does not have the lowest estimated emission fraction, it remains the recommended option for management in this phase, because of its potential to reduce use of water and fracturing fluid products.*

Table 2b) Summary of estimated emissions to water at each phase of hydraulic fracturing

Operation	Relevant section of report	Estimated Emissions (%)			
		Fracturing fluid product			Proppant
Transport	5.1	0			0
Storage and handling	5.2	0			0
Handling and blending	5.3	0			0
Injection of fluid	5.4	0			0
Subsurface fracturing	5.5	0			0
Treatment of recovered fluid	5.6	0			0
Waste:					
re-use (on-site)	5.2 & 5.7a	0			0
disposal (off-site)	5.7 b	0	75*		0
injection	5.7 c			0	0
Total emissions per fracture		0	75		
Average emissions to water per day		**0**	**5.8**	**0**	**0**
Prior to treatment.					

7. Generic exposure scenarios for hydraulic fracturing fluid product and proppant coating

The following values may be used to create an exposure scenario for the use of chemical substance in high-volume hydraulic fracturing operations. They are intended to be used as a starting point for exposure assessments in the absence of specific data.

If specific data are available, these should be used in preference to the generic information presented here.

Table 3) Generic exposure scenarios for hydraulic fracturing fluid product and proppant coating

		Use of substance in hydraulic fracturing fluid	Use of substance in proppant coating	Treatment of returned water via WWTP [a]
Amount used	Annual site tonnage/kg	2000	23000	2000
	Daily site tonnage/kg	2000	23000	116
Frequency and duration of use	Emission days per year	4	2	13
Environmental Factors not influenced by risk management	Local freshwater dilution	n/a	n/a	10
	Local marine dilution	n/a	n/a	100
Operational Conditions of use affecting environmental exposure	Release fraction to air from process (% per day)	0.9 [b]	0.025	0.3
	Release fraction to waste water from process (% per day)	0	0	5.8
	Release fraction to soil from process (% per day)	0	0	0
Organization measure to prevent /limit release from site				Do not apply industrial sludge to natural soils
Assumed waste water treatment plant flow m^3/day				20000

[a] *Additional release fractions and operating conditions accounting for discharge of returned water via waste water treatment works. Note that the daily emission factor accounts for 75% return of product from the formation, therefore should be applied to the whole tonnage of substance used (2000 kg).*

[b] *Release fraction to air includes re-use of fracturing fluid.*

8. Conclusions

Hydraulic fracturing is a well-established process that is supported by a series of best practices and guidelines which ensure that local emissions to water and soil are prevented by site containment and wellbore construction measures. Releases to air that result in emissions to soil and water may occur but will be accounted for in environmental risk assessment models.

Key factors that contribute to emission management include:

- the use of interceptors and secondary containment which prevents direct exposure to soil and surface water as well as downward migration of fracturing fluid products that may be released through leaks or spills
- fracturing fluid products only make up a small proportion of the total fracturing fluid minimising the impact of any potential releases
- the use of closed injection systems
- best practices in well completion which help to ensure wellbore integrity. Effective wellbore integrity provides a physical barrier between hydrocarbons and any injected fracturing fluid products and the surrounding rock strata
- fracture propagation is controlled and limited. The geology and physical separation between the targets of hydraulic fracturing and shallow water aquifers ensures releases are not plausible.

It is important that industry and authorities maintain a dialogue and cooperate to address public concerns, through the transparent sharing of information and knowledge.

IOGP, EOSCA and Cefic are key supporters of ngsfacts.org [2] which provides a platform for industry within the European Economic Area to voluntarily disclose fracturing fluid products on a well by well basis. Whilst chemical substances used in high-volume hydraulic fracturing are already subject to the requirements of REACH IOGP, EOSCA and Cefic will continue to cooperate with the EU Commission to improve REACH registration dossiers (where required) and raise awareness of how the REACH regulation applies to substances used within fracturing fluid.

This report provides the basis for the SpERC for high-volume hydraulic fracturing. Each phase of the hydraulic fracturing process has been reviewed, and it has been established that if the controls specified are in place that emissions are minimal. This allows suppliers to demonstrate that their substances can be used in the onshore exploration and production of hydrocarbons (such as shale gas) in an environmentally sound way.

The technology used in high-volume hydraulic fracturing is well established and industry has been using and developing this and similar techniques for decades. Experience demonstrates that effective implementation of current legislation, guidelines and established industry practices minimizes potential environmental releases and ensures that the environment is protected.

Glossary of terms

aboveground

Situated or taking place on or above the surface of the ground.

abandonment

Of a well: to permanently close a well, usually after determining that there is insufficient hydrocarbon potential to complete the well, or after production operations have drained the target formation. An abandoned well is plugged in accordance with regulatory requirements and industry practice to isolate the wellbore and the target formation.

aquifer

A zone of permeable, water saturated rock material below the surface of the earth capable of producing significant quantities of water.

bactericide /biocide

A substance that kills (micro-)organisms.

barrier layers

Relatively impermeable layer of rock between a formation and an aquifer.

Best Available Techniques (BAT)

Means the most effective and advanced methods/activities/techniques to prevent, or where not practicable, reduce emissions and the impact on the environment as a whole.

BTEX

Benzene, toluene, ethyl benzene and xylene.

breaker

A chemical used to reduce the viscosity of a fluid (break it down) after the thickened fluid has finished the task it was designed for.

brine

Water containing elevated levels of dissolved solids such as salts.

cap rock

Rock/or other material which is used to plug an abandoned well in accordance with regulatory requirements and industry practice to isolate the wellbore and the target formation.

casing

Large steel pipe used to 'seal off' or 'shut out' water and prevent caving of loose gravel formations when drilling a well. When the casings are set and cemented, drilling continues through and below the casing with a smaller bit. The overall length of this casing is called the casing string. More than one string inside the other may be used in drilling the same well.

Cefic

European Chemicals Industry Council www.Cefic.org

completion

The activities and methods of preparing a well for production after it has been drilled to the target formation. This principally involves preparing the well to the required specifications; running in production tubing and its associated down hole tools, as well as perforating and stimulating the well by the use of hydraulic fracturing, as required.

corrosion inhibitor

A chemical substance that minimizes or prevents corrosion in metal equipment.

crosslinker

A compound, typically a metallic salt, mixed with a base-gel fluid, such as a guar-gel system, to create a viscous gel used in some stimulation or pipeline cleaning treatments. The cross-linker reacts with the multiple strand polymer to couple the molecules, creating a fluid of high viscosity.

EOSCA

European Oilfield Speciality Chemicals Association www.EOSCA.eu

emission

The direct or indirect release of substances, vibrations, heat or noise from individual or diffuse sources into the air, water or land.

exploration

Drilling into a prospect and all related oil and gas operations necessary prior to production related operations.

fault

A fracture or fracture zone along which there has been displacement of the sides relative to each other.

flaring

Controlled burning of natural gas. The process is typically used as an alternative to venting, e.g. during the well completion phase.

flowback fluid (flowback water)

Generally defined as "fluid returned to the surface after hydraulic fracturing has occurred, but before the well is placed into production". It typically consists of returned fracturing fluids following hydraulic fracturing which are progressively replaced by produced water". [32] According to the US EPA, "flowback," is a subset of produced water. The definition of flowback is not considered to be standardized. Generally, the flowback period in shale gas reservoirs is several weeks [33].

formation

A rock body distinguishable from other rock bodies and useful for mapping or description. Formations may be combined into groups or subdivided into members.

formation water

Water that occurs naturally within the pores of rock.

fracking

Informal abbreviation for "hydraulic fracturing".

fracturing fluid

Fluid used to perform hydraulic fracturing. This fluid is pumped into the wellbore and formation at a pressure sufficient to generate a crack or fracture in the target formation. This enhances the formation's exposed surface area improving flow and resulting in increased production compared to the unfractured formation. Fracturing fluid is designed to take into account the specific area and rock type being fractured.

fracturing fluid products

Components within fracturing fluid which are selected to impart a predictable set of properties to the fluid, including viscosity, friction, formation-compatibility, and fluid-loss control.

free-flow

A well in which the formation pressure is sufficient to produce oil or gas at a commercial rate without requiring a pump.

friction reducer/friction reducing agent

A chemical additive which alters the hydraulic fracturing fluid allowing it to be pumped into the target formation at a higher rate and reduced pressure.

gelling agent

Polymers used to thicken fluid so that it can carry a significant amount of proppant into the formation.

green completion

Also known as reduced emissions completion (REC), term used to describe a practice that captures gas produced during well completions and well workovers following hydraulic fracturing. Portable equipment is brought on-site to separate the gas from the solids and liquids produced during the high-rate flowback, and produce gas that can be delivered into the sales pipeline. RECs help to reduce methane, volatile organic compounds (VOC), and polycyclic aromatic hydrocarbons (PAH) emissions during well clean-up and can eliminate or significantly reduce the need for flaring.

groundwater

All water which is below the surface of the ground in the saturation zone and in direct contact with the ground or subsoil.

hazardous

Something that is harmful to humans or the environment.

High-volume hydraulic fracturing (HVHF)

The stimulation of a well (normally a shale gas well using horizontal drilling techniques with multiple fracturing stages) with high-volumes of fracturing fluid. Defined as fracturing using 1000 m^3 or more of water per stage or 10,000 m^3 or more of water during the entire fracturing process of a well.

horizontal drilling

Deviation of the borehole from vertical so that the borehole penetrates a productive formation with horizontally aligned strata, and runs approximately horizontally.

hydraulic fracturing

The process by which fracturing fluids – a mixture consisting primarily of water, sand and a small percentage of chemical substances (typically 0.5%) [6, 7] are injected under high pressure into a geological formation that contains hydrocarbons so as to break the rock and to connect the pores that trap the hydrocarbons.

hydraulic fracturing fluid

Fluid used to perform hydraulic fracturing; includes the primary carrier fluid, proppant material, and all applicable additives.

hydrocarbon

A compound formed essentially of carbon and hydrogen.

hydrocarbon reservoirs

A subsurface pool of hydrocarbons contained in porous or fractured rock formations. The naturally occurring hydrocarbons, such as crude oil or natural gas, are trapped by overlying rock formations with lower permeability.

migration

Movement of fracturing fluid or gas though the surrounding rock formations.

Mining Waste Directive

EU Directive 2006/21/EC on the management of waste from extractive industries [34]

NORM

Naturally Occurring Radioactive Materials. Low-level radioactivity that can exist naturally in native materials.

permeability

A measure of a material's (e.g. rock's) ability to allow passage of gas or liquid through pores, fractures, or other openings. The SI unit of measurement is m^2, although a frequently used unit is the Darcy or millidarcy.

polymer

Chemical compound of unusually high molecular weight composed of numerous repeated, linked molecular units.

produced water

Generally defined as "fluids displaced from the geological formation, which can contain substances that are found in the formation, and may include dissolved solids (e.g. salt), gases (e.g. methane, ethane), trace metals, naturally occurring radioactive elements (e.g. radium, uranium), and organic compounds" [32]. According to the US EPA, there is no clear transition between flowback and produced water.

Propagate (fracturing)

Growth of the fracture through the surrounding rock formations.

proppant or propping agent

A granular substance (e.g. sand grains, ceramics, aluminium pellets, or other material) that is carried in suspension by the fracturing fluid and that serves to keep the cracks open when fracturing fluid is withdrawn after a fracture treatment. Proppant may be coated or uncoated.

REACH

REACH is a European Union regulation concerning the Registration, Evaluation, Authorization & Restriction of Chemicals (Regulation (EC) No 1907/2006) [35]

receptor

Something which could come to harm, including human health, water resources, surface water courses or the wider environment.

sand tower

Vertical silo or tank used for storing proppant.

scale inhibitor

A chemical substance which prevents the accumulation of a mineral deposit (for example, calcium carbonate) that precipitates out of water and adheres to the inside of pipes, heaters, and other equipment.

shale

Sedimentary rock consisting of thinly laminated claystone, siltstone or mud stone. Shale is formed from deposits of mud, silt, clay, and organic matter laid down in calm seas or lakes.

shale gas

Natural gas that remains tightly trapped in shale and consists chiefly of methane, but with ethane, propane, butane and other organic compounds mixed in.

SpERC

A SpERC contains the description of a set of use conditions (operational conditions (OC) and risk management measures (RMM)) connected an activity/technique/process (i.e. to be used in a Chemical Safety Assessment for REACH).

stimulation

The act of increasing a well's productivity by artificial means such as hydraulic fracturing or acidizing.

subsurface

Situated or taking place below the surface of the ground.

surfactant

A chemical substance/mixture which reduces surface tension.

TDS

Total dissolved solids.

UKOOG

United Kingdom Onshore Operators Group http://www.ukoog.org.uk/

well/wellbore

A borehole; the hole drilled by the bit. A wellbore may have casing in it or it may be open (uncased); or part of it may be cased, and part of it may be open.

wellbore clean up

Removal of drilling fluids other debris prior to completing the well.

wellhead

The equipment installed at the surface of the wellbore. A wellhead includes such equipment as the casing head and tubing head.

Appendix A – European exploration wells data

Operator(s)	Well	Water		Proppant		% Water & prop.	Hydraulic fracturing products	
		Vol (m³)	%	Mass (kg)	%		%	Vol (m³)
Conoco Phillips / Lane Energy	Strzeszewo LE-1 (stage 1)	593.97	89.45%	57227	8.60%	98.06%	1.94%	12.9
Lane Energy / Conoco Phillips	Lebien LE-1	1452.2	94.08%	86401	5.61%	96.69%	3.31%	51.1
Lane Energy / Conoco Phillips	Warblino LE-1H	4186.4	84.37%	604239	12.39%	96.76%	3.24%	160.8
ExxonMobil Expl. & Prod. Poland	Siennica-1	2016.32	74.20%	184218	6.90%	81.06%	18.94%	514.7
ExxonMobil Expl. & Prod. Poland	Krupe-1	2583.2	84.68%	224200	7.46%	92.14%	7.86%	239.8
Lane Energy / Conoco Phillips	Lebien LE-2H	17571	92.73%	1292487	6.79%	99.52%	0.48%	91.0
Marathon Oil Polska	KWI-Prabuty-01	352	89.44%	26750	9.62%	99.06%	0.94%	3.7
Chevron Polska Energy Resources	Zwierzyniec 1	1248	92.44%	49871	3.69%	96.13%	3.87%	52.2
Marathon Oil Polska	RYP-Lutocin-01	250.7	97.89%	1737	0.76%	98.65%	1.35%	3.5
Marathon Oil Polska	ORZ-Cycow-01	540	89.95%	40750	9.22%	99.17%	0.83%	5.0
Conoco Phillips / Lane Energy	Strzeszewo LE-1 (stage 2)	646.1	82.60%	136917.2	13.70%	96.30%	3.70%	28.9
Eni Polska Zoo	Stare Miasto 1H	3265	93.04%	199311	5.75%	98.79%	1.21%	42.5
Lane Energy	Lublewo LEP-1ST1H	16826.9	81.99%	3457739	16.97%	98.96%	1.04%	213.4
Orlen Upstream	Syczyn-OU2K	38134.7	96.32%	1392892	3.55%	99.87%	0.13%	51.5
Orlen Upstream	Berejow-OU2K	22499	94.54%	1101477	4.67%	99.20%	0.80%	190.4
Eni Polska Zoo	Stare Miasto-1k	3212	93.60%	199311	5.50%	99.10%	0.90%	30.9
Wisent Oil & Gas	Babiak 1H	1425.65	93.23%	91308.14	5.975%	99.21%	0.79%	12.1
Wisent Oil & Gas	Rodele-1	1535.61	89.08%	176238.8	10.23%	99.31%	0.69%	11.9

Operator(s)	Well	Water		Proppant		% Water & prop.	Hydraulic fracturing products	
		Vol (m^3)	%	Mass (kg)	%		%	Vol (m^3)
BNK Petroleum [a]	Gapowo B-1A (20 Stages)	25360.58	97.26%	591450	2.27%	99.53%	0.47%	122.6
San Leon Energy	Lewino 1G2	4685.8	94.54%	209802	5.42%	99.96%	0.04%	2.0
Saponis Investments	Lębork S-1 (Stage1)	896	99.71%	43600	0.05%	99.76%	0.24%	2.2
Saponis Investments	Lębork S-1 (Stage 2)	620	99.88%	26183	0.04%	99.92%	0.08%	0.5
Polskie Górnictwo Naftowe i Gazownictwo SA	Lubocino 2H	7963.91	89.92%	no data	7.52%	97.44%	2.56%	226.7

SUMMARY	Water (m^3)		Proppant (kg)		Water & Prop	Hydraulic Fracturing Products (m^3)	
Range	250 – 38100	74.2 – 99.9 %	1740 – 3457700	0 – 17 %	81.1 – 100 %	0.5 – 515	0 – 18.9 %
Mean	6023	90.8 %	457269	6.84 %	97.5 %	89	2.5 %
St. Dev	9510.38	0.06225	807402.9	0.04205	0.04097	125.247	0.04097
	Mean volume of hydraulic fracturing fluid (water + proppant + hydraulic fracturing product) = 6633 m^3/site						

[a] BNK Petroleum's Gapowo B-1A well was reported as a total of 20 Stages, these data have not been included in the summary statistics because a breakdown of the data by stage was not available.

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Further reading

A significant amount of evidence and a significant number of studies have been produced and we would be pleased to provide you with any additional information and/or clarification that you may require.

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This report assesses the level of environmental exposure to the chemical products used in the exploration and production of hydrocarbons using high-volume hydraulic fracturing – such as shale gas.

The report was developed jointly by the International Association of Oil & Gas Producers (IOGP), the European Oilfield Specialty Chemicals Association (EOSCA) and the European Chemical Industry Council (CEFIC).