PROJETO MA-09 (CTMA/PROMINP)

Workshop Técnico sobre O&G Não-convencionais

Environmental Risks and Regulation of Shale Gas in UK and Europe: Research Review

25th November 2014, MME, Brasilia

Overview

1. Amec foster wheeler…at a glance
2. Overview of environmental risks and regulation of shale gas in UK and Europe: Research Review
3. Key issues
    1. Water resources – surface and subsurface contamination risks
    2. Water resources - demand management
    3. Solid and liquid wastes, such as drill cuttings and flowback water
    4. Induced seismicity
    5. Gas emissions (including methane)
4. Concluding thoughts

Amec foster wheeler at a glance

FTSE 100
company

Revenue some
£5.5 billion*

- Oil and gas 56%
- Clean Energy 27%
- Environment and Infrastructure 9%
- Mining 8%

Employees some
40,000

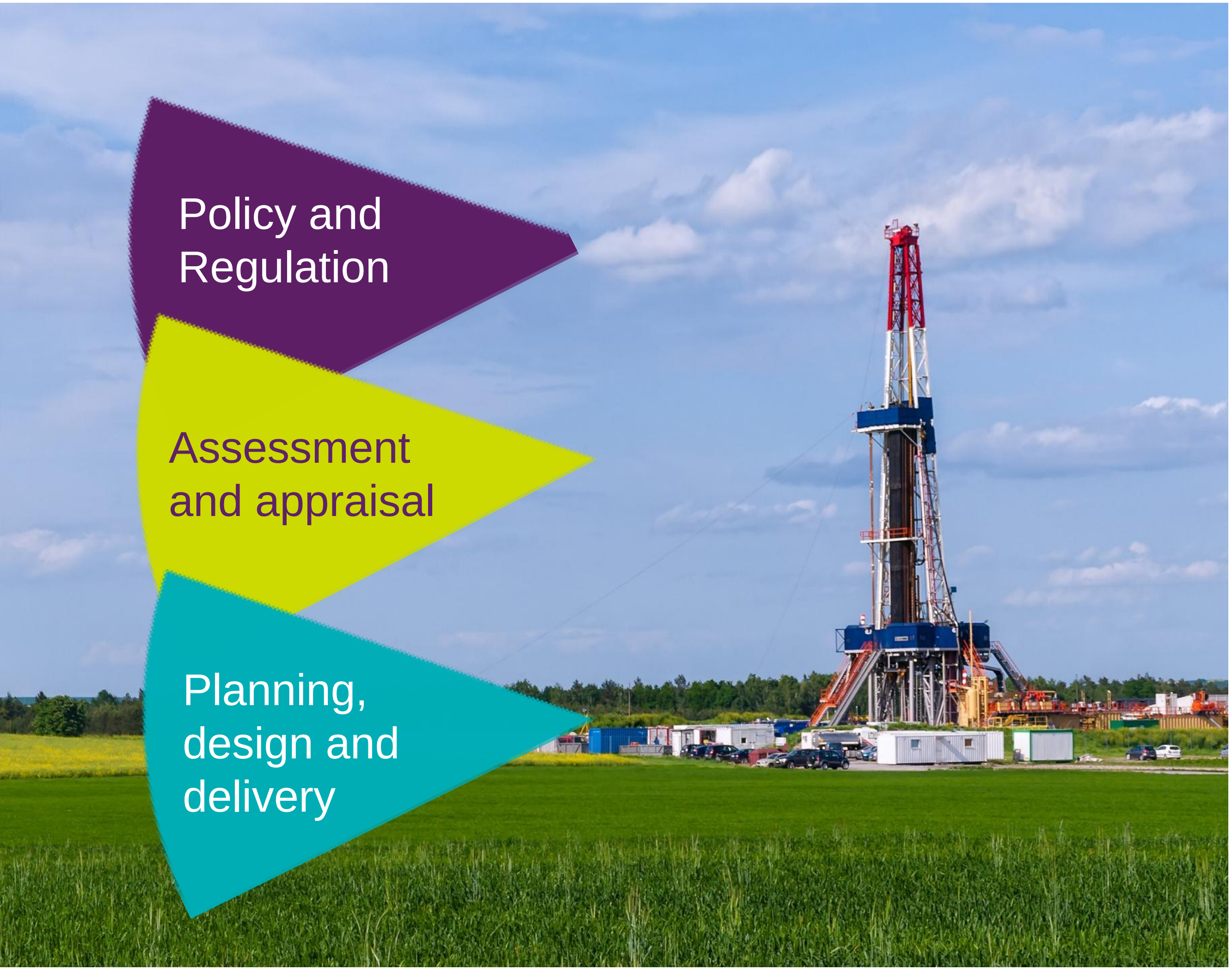
- Europe 13,000
- Americas 17,000
- Africa, Middle East and Asia 8,400
- Global Power Group 2,000

Operating in over
50 countries
and serving following markets:

- Oil & Gas
- Mining
- Clean Energy
- Power Generation
- Pharma
- Environment & Infrastructure

* As at November 2014

Our Environmental Expertise



Golden Rules for A Golden Age of Gas

“Shale gas is posed to enter a golden age…but will only do so if it can be done profitably and in an environmentally acceptable manner…. numerous hurdles need to be overcome, not least the social and environmental concerns associated with its extraction…. there is a critical link between the way that governments and industry respond to these social and environmental challenges and the prospects for unconventional gas production”

IEA 2012

Research Overview

Terms of reference:

- What are the likely significant effects and principal risks associated with hydraulic fracturing as a means to extract shale gas?
- Can these effects be effectively avoided, minimised or mitigated to ensure that the risks to the environment and human health can be effectively managed?
- What regulations are used in the UK and Europe to address the specific risks to the environment and human health from hydraulic fracturing?
- What lessons can be learned from the regulatory frameworks employed in UK and Europe to the management of risks associated with hydraulic fracturing that could be relevant to the Brazilian context?

Methods

Included:

- Research of publicly available peer reviewed information;
- Drawing on outputs and experience from work for the EC, regulators and industry;
- Workstreams covering effects, mitigation, regulation and relevance for Brazil;
- Qualitative commentary from stakeholders;
- Peer review.

Topics

Risks and effects on:

- Biodiversity and nature conservation;
- Land use;
- Geology (including induced seismicity);
- Water resources (included increased demand, and potential contamination of surface and ground water);
- Air quality;
- Climate change (included fugitive methane emissions);
- Waste arisings (including consideration of solid and liquid wastes, such as drill cuttings and flowback water);
- Cultural heritage (included archaeology);
- Landscapes;
- Human health.

Sources include…

- **AEA (2012a) Support to the identification of potential risks for the environment and human health arising from hydrocarbons operations involving hydraulic fracturing in Europe. European Commission, DG Environment.**
- AEA (2012b) Climate impact of potential shale gas production in the EU. European Commission, DG Clima.
- **AMEC (2013), Strategic environmental assessment for further onshore oil and gas licensing.**
- AMEC (2013), Understanding the potential impacts of shale gas fracking on the UK water industry, Report Ref. No. WR09C301.
- **AMEC (2013), Technical support for assessing the need for a risk management framework for unconventional gas extraction.**
- Davies, R.J., Foulgar, G., Bindley, A., Styles, P. (2013) What size of earthquakes can be caused by fracking?
- DCLG (2013), Planning practice guidance for onshore oil and gas.
- DNV (2013) Risk management of shale gas developments and operations.
- EA (2012) Monitoring and control of fugitive methane from unconventional gas operations, Environment Agency.
- EC(2011), Impacts of shale gas and shale oil extraction on the environment and on human health.
- **EC (2014), Exploration and production of hydrocarbons (such as shale gas) using high volume hydraulic fracturing in the EU, Impact Assessment SWD(2014) 21 final.**
- ENDS (2013), UK shale gas and the environment: The real environmental implications of fracking and the key sustainability challenges facing a future UK onshore shale energy industry.
- Green AC, Styles P and Baptie BJ (2012) Preese Hall shale gas fracturing review and recommendations for induced seismic mitigation, DECC.
- House of Commons Energy and Climate Change Committee (2011), Shale Gas, Committee's Fifth Report of Session 2010–12 (HC 795).
- House of Commons Energy and Climate Change Committee (2013) The Impact of Shale Gas on Energy Markets: Seventh Report of Session 2012–13, Volume I.
- House of Lords Economic Affairs Committee (2014), The Economic Impact on UK Energy Policy of Shale Gas and Oil, 3rd Report of Session 2013–14.
- JRC (2012), Shale Gas for Europe – Main Environmental and Social Considerations A Literature Review, Boyan Kavalov and Nathan Pelletier.
- **Mackay and Stone (2013) Potential greenhouse gas emissions associated with shale gas extraction and use. DECC.**
- PHE (2013) - Review of the potential public health impacts of exposures to chemical and radioactive pollutants as a result of the shale gas extraction - Draft for comment, October 2013. Public Health England.
- **The Royal Society and Royal Academy of Engineering report, Shale gas extraction in the UK: a review of hydraulic fracturing June 2012.**
- **UKOOG (2013) UK Onshore shale gas well guidelines: exploration and appraisal phase. UK Onshore Operators Group.**

Water Resources

Contamination

What are the Risks and Effects?

Surface Spills	
Risks	Surface spills of fracturing and other fluids including drilling muds/cuttings, flowback and produced water entering ground and surface water bodies
Causes	Well ‘blowouts’, vehicle accidents, inadequate storage of hydraulic fracturing fluids and flowback water
Likelihood	Medium/High – one of the main causes of water contamination in the US (US EPA, 2012)
Residual Risk	Unlikely to be significant, if control and mitigation measures are implemented.

Control and Mitigation

Surface Spills

- Require surface hydrology and flood risk assessments to identify and categorise pathways, barriers and the potential risk of flooding to/from a site and appropriate mitigation.
- Surface Water Management Plans should be prepared setting out measures for controlling runoff including, for example, the installation of drainage channels.
- The well pad should be constructed from compacted aggregate laid on an impermeable membrane and geotextile layer. Surface water runoff would be collected and attenuated via perimeter ditches. There should be no connectivity between the runoff ditches from the well pad and any other surface water features adjacent to the well pad. Onsite storage facilities should also be bunded where appropriate.
- Require Accident Management Plan to be developed and spill kits provided to ensure the prevention/containment of accidental spills; ensure training on use of spill kits.
- Require good site practice to prevention of leaks and spills.
- Require Accident Management Plan to be developed and spill kits provided to ensure the prevention/containment of accidental spills; ensure training on use of spill kits.
- Require tank level alarms.
- Require double skinned closed storage tanks.

Control and Mitigation

Surface Spills

- Avoid the use of persistent, bio-cumulative and toxic, carcinogenic and mutagenic chemicals.
- Require good site security.
- Characterisation of drilling muds.
- Disclosure of information on drilling muds to competent authority.
- Use of closed loop system to contain drilling mud.
- Use closed tanks for mud storage.
- Restrict muds to approved list with known properties/safety data or non-toxic drilling muds.
- Require accounting / tracking of mud use.

Regulations

Include:

EU

- Water Framework Directive
- Mining Wastes Directive

UK

- Environmental Protection Act, Environmental Protection (Prescribed Processes and Substances) Regulations 1991
- Water Resources Act 1991
- Town and Country Planning (Environmental Impact Assessment) Regulations
- Environmental Permitting Regulations
  - a water discharge activity – if surface water run-off becomes polluted, for example, due to a spill of diesel or flowback fluid.

Lessons Learned

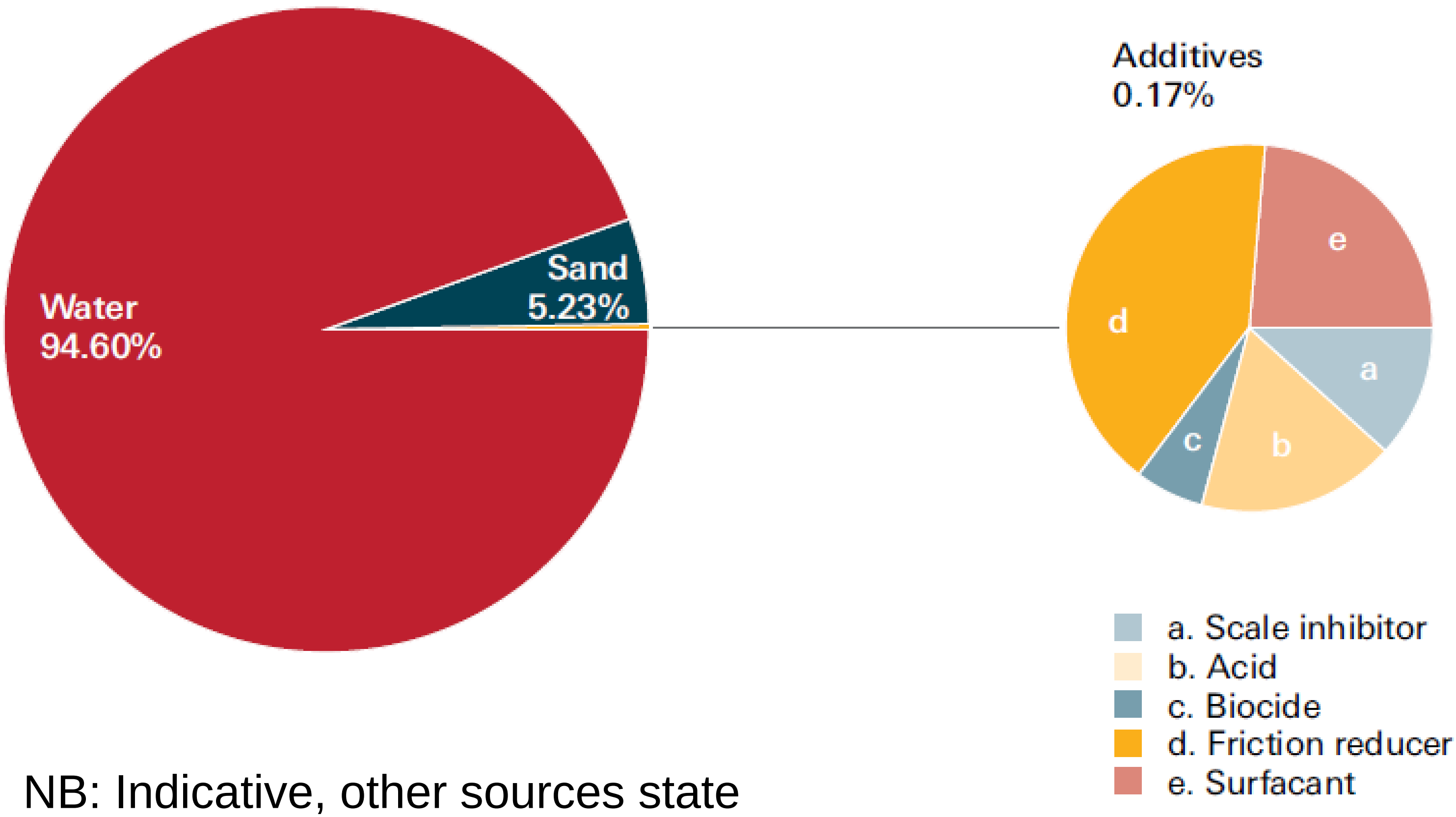
Include:

- Importance of considering source-pathway-receptor in modelling effects.
- Importance of EIA and design (multiple barriers to prevent spills).
- Value of Surface Water Management Plans and Accident Management Plans.
- Use of non-toxic, low toxicity chemicals.
- Use of closed loop systems.
- Importance of Environmental Management Systems and staff training.

What are the Risks and Effects?

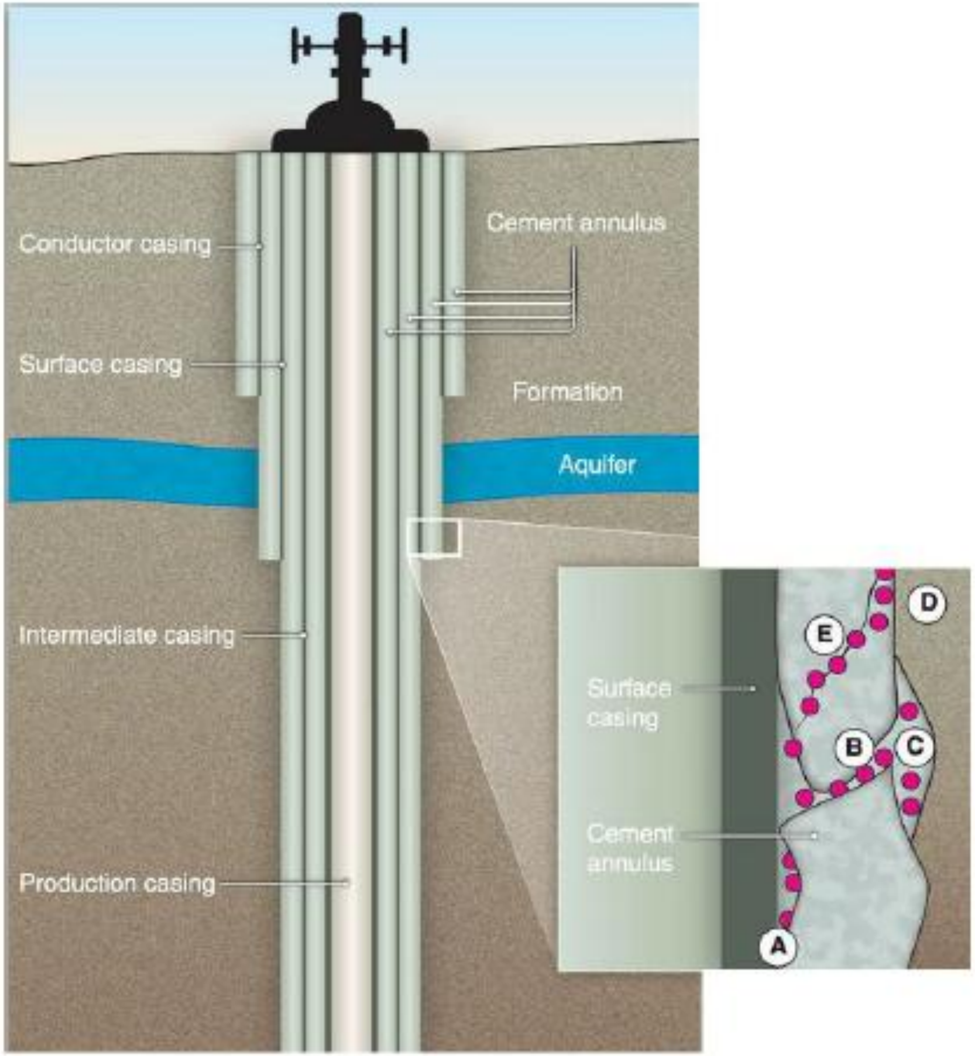
Surface water and groundwater contamination (Leakage)	
Risks	Subsurface leakage of fracturing fluid, produced water (including NORM and methane) to groundwater and, potentially, surface water.
Causes	-Inadequate control and design of drilling -Subsurface well ‘blowouts’ -Loss of well integrity due to poor casing design and cementation quality -Movement of contaminants through existing faults -Inadequate spacing between fracture zone and aquifers
Likelihood	Low/medium given existing industry standard practice, particularly if operations are properly regulated.
Residual Risk	Unlikely to be significant, assuming control and mitigation measures are implemented.

Composition of Fracturing Fluid



NB: Indicative, other sources state up to 99% water used (King, 2012)

Well Integrity: Pollution Pathways



A: between cement and casing
B: through fractures
C: through gaps
D: between cement and formation
E: through cement

What are the Risks and Effects?

Surface water and groundwater contamination (Leakage)	
Risks	Subsurface leakage of fracturing fluid, produced water (including NORM and methane) to groundwater and, potentially, surface water.
Causes	-Inadequate control and design of drilling -Subsurface well ‘blowouts’ -Loss of well integrity due to poor casing design and cementation quality -Movement of contaminants through existing faults -Inadequate spacing between fracture zone and aquifers -Uncontrolled fracture propagation
Likelihood	Low/medium given existing industry standard practice, particularly if operations are properly regulated.
Residual Risk	Unlikely to be significant, assuming control and mitigation measures are implemented.

Control and Mitigation

Surface water and groundwater contamination (Leakage)

- Maintain multiple barriers between the target formation and people/the environment.
- Require minimum vertical distance between hydraulic fracture pipes and geological strata containing aquifers (e.g. ~600m) and the surface (e.g. <600m depth requires special permit). (ref. Davies et al 2012).
- Permits should require information relating to (inter-alia), the relationship between the zone of interest and any overlapping or adjacent aquifers, methods of well construction, well integrity testing, where the well stimulation fluid is expected to travel, details of the liquids to be injected, water use and disposal of effluents.
- Undertake desk study and document potential leakage pathways (e.g. other wells, faults, mines) in sphere of influence of drilling and HF to inform development of conceptual hydrogeological model.
- A Hydraulic Fracturing Programme similar to that in operation in the UK should be prepared by the operator and agreed with the relevant regulator.
- Where possible, non-hazardous chemicals should be used in fracturing fluids.
- Consideration should be given to the development of a list of approved chemicals for use in fracturing fluids or, as in the UK, a methodology to enable regulators to assess the hazard potential of any chemicals used.

Control and Mitigation

Surface water and groundwater contamination (Leakage)
• Require development of a conceptual model of the zone before work commences covering geology, groundwater flows, pathways, microseismicity and subsequent updating of the model as information becomes available. • Require modelling of fracturing programme to predict extent of fracture growth based on best information. • Require microseismic and borehole monitoring and control during operations to ensure hydraulic fractures / pollutants do not extend beyond the gas-producing formations and does not result in seismic events. • Measures should be adopted to ensure well integrity including consultation on well design with appropriate regulators, bore testing, cement testing, the installation of a cement bond and continual pressure and formation pressure testing. The results of well integrity testing should be independently verified. • Require use of tracers to detect water contamination.

Control and Mitigation

Surface water and groundwater contamination (Leakage)

- Require integrity testing at key stages in well development e.g. before/during/after HF, including:
  - wireline logging (calliper, cement bond, variable density)
  - pressure / hydrostatic testing)
  - mechanical integrity testing of equipment (MIT).
- Require key elements to maintain well safety such as:
  - blowout preventers, pressure & temperature monitoring and shutdown systems, fire and gas detection, continuous monitoring for leaks and release of gas and liquids, modelling to aid well/HF design, real-time monitoring of HF (such as microseismic surveys)
  - casings: minimum distance the surface casing extends below aquifer (e.g. 30m below the deepest underground source of drinking water encountered while drilling the well, ref. Environment Agency 2012) and surface casing cemented before reaching depth of 75m below underground drinking water (ref. AEA 2012). Production casing cemented up to at least 150 metres above the formation where hydraulic fracturing will be carried out (ref. AEA 2012).
- Implement remedial measures if well failure occurs and/or abandon well safely.
- These should include details of any monitoring to be undertaken following well abandonment and the means of well plugging.

Regulations

Include:

- As for surface water contamination
- Notice required under the Water Resources Act to ‘construct a boring for the purposes of searching for or extracting minerals’
- Environmental Permitting Regulations requires an environmental permit. Operators should submit the following information:
  - a conceptual model showing the hydrogeological relationship between the zone of interest and any overlying or adjacent aquifers;
  - the method of well construction, including details of the casing and grouting;
  - information on how the integrity of the casing is to be tested;
  - information on the location of the proposed operation and where the well stimulation fluid is expected to travel to;
  - details of the liquids to be injected, water ingress, water use and disposal of effluents;
  - details of any chemicals added in the process or substances used to prop open fissures;
  - safeguards to prevent cross-contamination of aquifers;
  - safeguards to prevent uncontrolled loss of fluids in the borehole to formations or ground surface (blowouts);
  - potential quality risks to receptors and groundwater resources;
  - details of how the operation itself is to be monitored;
  - proposed environmental monitoring (including monitoring groundwater and surface water receptors).

Lessons Learned

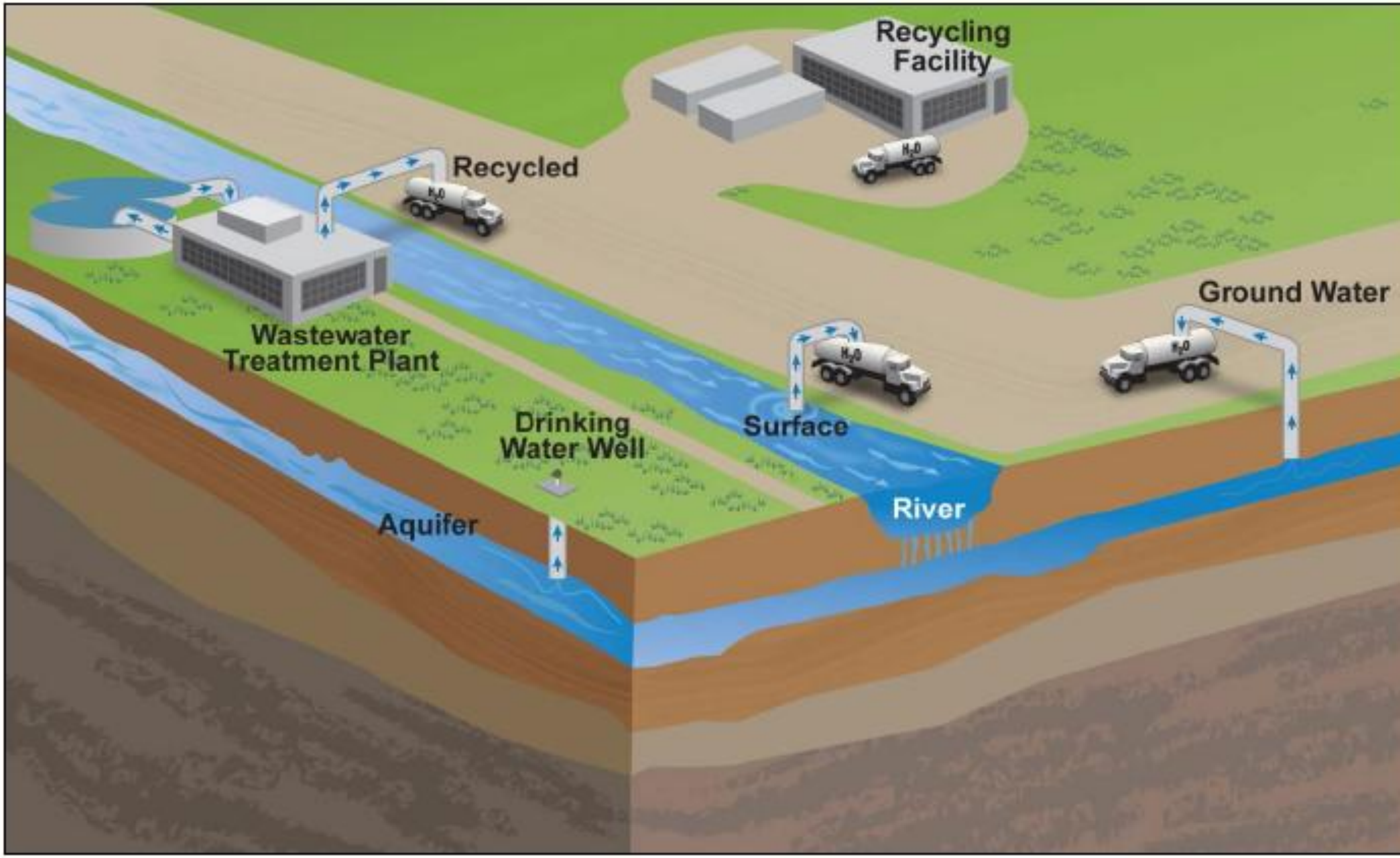
Include importance of:

- Maintain multiple barriers between the target formation and people/the environment.
- Require minimum vertical distance between hydraulic fracture pipes and geological strata containing aquifers.
- Establish the relationship between the zone of interest and any overlapping or adjacent aquifers, methods of well construction, well integrity testing, where the well stimulation fluid is expected to travel, details of the liquids to be injected, water use and disposal of effluents.
- Require development of a conceptual model of the zone before work commences covering geology, groundwater flows, pathways, microseismicity and subsequent updating of the model as information becomes available.
- Monitor fracture growth
- Require a Hydraulic Fracturing Programme
- Where possible, non-hazardous chemicals should be used in fracturing fluids.
- Measures should be adopted to ensure well integrity including integrity testing at key stages in well development e.g. before/during/after HF.
- Measures to detect water contamination.

Water Resources

Demand Management

Water Sources



What are the Risks and Effects?

Water Resource Demand	
Risks	Unsustainable extraction of groundwater and/or surface water leading to: water scarcity; adverse impacts on water quality and aquatic ecology; bacterial growth; interplay with downstream discharges; impacts on hydrology and hydrodynamics altering the flow regime and water quality; upwelling of lower quality water or substances into aquifer; subsidence and destabilisation of geology.
Causes	-Abstraction of groundwater leading to lowering of water table; -Release of biogenic methane into superficial aquifers; -Potential cumulative effects of large numbers of operations, (particularly in drought and dry periods); -Abstraction of surface water.
Likelihood	Medium/low. Dependent on: -The timing of the consumption of the water; -Number of sites in one area; -Existing water resources and users; -The volume of waste water than can be recycled/reused.
Residual Risk	Unlikely to be significant, if control and mitigation measures are implemented

Control and Mitigation

Water Resource Demands
• Careful consideration should be given during site selection to water resource availability, in liaison with water providers and regulators. • Operator to produce demand profile for development of well field, identifying intended sources of water and notifying the regulator and water provider. • The operator and the relevant regulator(s) should assess the potential impacts on water resources at an early stage. • Require water management plan, with water demand profile modified to reflect development of gas play. • Options to reduce water demand during hydraulic fracturing should be considered where possible. This may include the treatment and re-use of flowback water or the adoption of waterless technologies. • Require use of lower quality water for fracturing (e.g. non-potable ground / surface water or rainwater harvesting).

Control and Mitigation

Memorandum of Understanding

- Ensures respective members will cooperate throughout the shale gas exploration and extraction process in order minimise adverse effects on water resources and the environment.
- Under the MoU, members of UKOOG and Water UK will undertake timely consultation and discussion in orderto identify and resolve risks around water resource availability.

Regulations

Include:

EU

- Water Framework Directive

UK

- Water Resources Act requires a water abstraction licence if more than 20 m3/day used. Information required will include:
  - details of the sources of water to be abstracted, the feasibility of doing so and the suitability of the source
  - information on the quantities of water to be used and the purpose for which they will used
  - an assessment of the potential effects on the environment and other water users, including other abstractors
  - hydrological and hydrogeological information

Lessons Learned

Include:

- Importance of considering site selection and water resource availability
- Require water management plan, with water demand profile modified to reflect development of gas play.
- Options to reduce water demand during hydraulic fracturing should be considered where possible. This may include the treatment and re-use of flowback water or the adoption of waterless technologies.
- Use of lower quality water for fracturing (e.g. non-potable ground / surface water or rainwater harvesting).

Waste Management

Solid and Liquid Wastes

Waste Streams and Management

Waste Stream	Category	Cuadrilla Planned Recovery/Treatment/Disposal Method
Polymer based water drilling muds	Non-hazardous	Recycled offsite where feasible. A small amount may be lost to formation. Residual waste to specialist disposal facility.
Drill cuttings used with polymer based water muds	Non-hazardous	Treatment at a specialist facility. Residual waste to specialist disposal facility.
Low-toxicitiy oil based emulsion drilling muds	Non-waste	Closed loop system, muds are reconditioned by the supplier for reuse. A small amount may be lost to formation.
Drill cuttings used with low-toxicity oil based emulsion muds	Hazardous	Treatment as hazardous waste. Residual waste to hazardous waste disposal facility.
Losses to formation	Non-hazardous / Hazardous	Cuadrilla unlikely to be able to recover losses to formation.
Cement waste from the well casing	Non-hazardous	Recycled where feasible. Residual waste to landfill.
Spacer fluid	Non-hazardous	Treatment offsite and disposal at a specialist site for liquids.
Any contaminated materials from remediating oil or diesel spills, oil from separators, various waste oils and lubricants	Hazardous	Treatment as hazardous waste. Recovery where feasible. Residual waste to hazardous waste disposal facility.
General waste e.g. paper, timber, scrap-metal, food waste	Non-hazardous	Recycling where feasible onsite. Materials Recovery Facility. Residual waste to landfill.
Wastewater (foul effluent)	Non-hazardous	Recovery at a local Wastewater Treatment Works.
Industrial wastewater (rainwater captured by the pad during drilling)	Non-hazardous	Recovery for treatment at a local Wastewater Treatment Works.
Flowback fluid	Radioactive – Non-hazardous	Reuse on site
Sand	Non-hazardous	Recycled into secondary aggregates
Solid scale	Radioactive Waste – Low Level Waste	Augean Low Level Waste facility
Materials and equipment contaminated by NORM	Radioactive Waste – Low Level Waste	Augean Low Level Waste facility
Surplus natural gas	Hazardous (highly flammable)	Flared onsite

Source: Cuadrilla Bowland Ltd (2014) Temporary Shale Gas Exploration Preston New Road, Lancashire: Environmental Statement

What are the Risks and Effects?

Waste water treatment	
Risks	Waste water arising including flowback and produced water, NORMs, drilling muds, drill cuttings, proppants removed from flowback fluid and waste gas cannot be managed/disposed of in appropriate treatment facilities leading to potential for spillages from storage, incomplete treatment leading to water contamination.
Causes	-Lack of appropriate treatment capacity. -Reinjection of untreated flowback -Failure of storage ponds -Surface spills -Venting of gas
Likelihood	Medium/High
Residual Risk	Potentially significant, with some uncertainties over availability of control and mitigation measures

Control and Mitigation

Management of Flowback and Produced Water

- Require management of flowback and produced water as part of required Waste Management Plan which will set out quantities and chemicals to be used and methods to encourage recovery and to ensure safe short- and long-term disposal
- Require double skinned closed storage tanks.
- Require spill kits.
- Require berm around site boundary.
- Require impervious site liner under pad with puncture proof underlay.
- Avoid the use of persistent, bio-cumulative and toxic, carcinogenic and mutagenic chemicals.
- Require accounting and tracking of fracking chemicals used.

Control and Mitigation

Management of Flowback and Produced Water

- Consider options for treatment and resuse of flowback fluid on site, for example through separation to remove sand, oil and gas, plus ultraviolet (UV) disinfection. Separated sand can be removed from site and recycled into aggregates.
- Ensure that flowback fluid/produced water containing NORM is treated using an approach that ensures environmental protection, and is not disposed of at wastewater treatment works that are unable to process radioactive waste. Options could include pre-treatment with acid-alkali to precipitate out NORM for disposal or treatment at a wastewater treatment site licensed to accept radioactive waste.
- Consider the use of reverse osmosis or evaporation and crystallisation to reduce levels of Total Dissolved Solids (TDS) in wastewater. [Elevated TDS levels may affect the functioning of the wastewater plant and potentially contaminate any receiving waters after discharge.]
- Once flowback and/or produced water considered waste water, identify treatment plant operator to accept wastes, taking into account treatability/loading and ability to meet their own discharge consent limits.
- If necessary, require dedicated wastewater treatment facility.
- Require duty of care / chain of custody arrangements for waste transfer.

Regulations

Include:

EU

- Water Framework Directive
- Mining Wastes Directive

UK

- Environmental Protection Act and Environmental Permitting Regulations require a Waste Management Plan covering:
    - Measures to prevent or reduce waste, and its harmfulness including recovery, and safe short- and long-term disposal;
    - Characteristics of each waste (inert, non-hazardous non-inert, or hazardous);
    - Estimated total quantities of waste to be produced when activities are carried out;
    - Measures necessary to prevent, or reduce as far as possible, any adverse effects on the environment and human health.

Lessons Learned

Include:

- Importance of early discussion between operators, regulators and treatment plant operatives and preparation of Site Waste Management Plans to determine waste arisings and appropriate treatment options/need for additional investment.
- Importance of prescribing and ensuring use of non-toxic chemicals.
- Importance of considering recycling and reuse options of flowback fluid, using an approach that ensures environmental protection.
- Importance of considering residual treatment options.

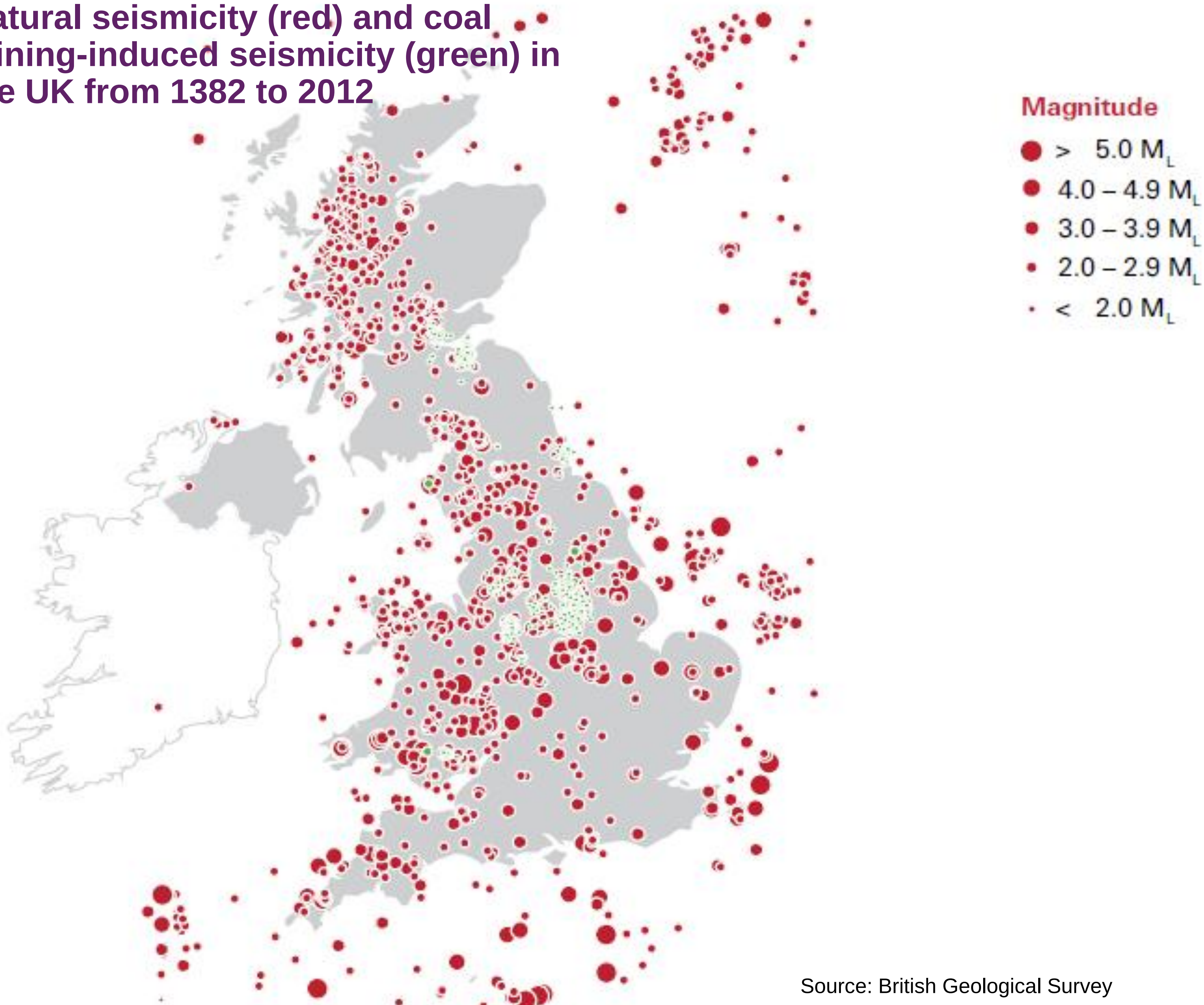
Geology

Induced Seismicity

What are the Risks and Effects?

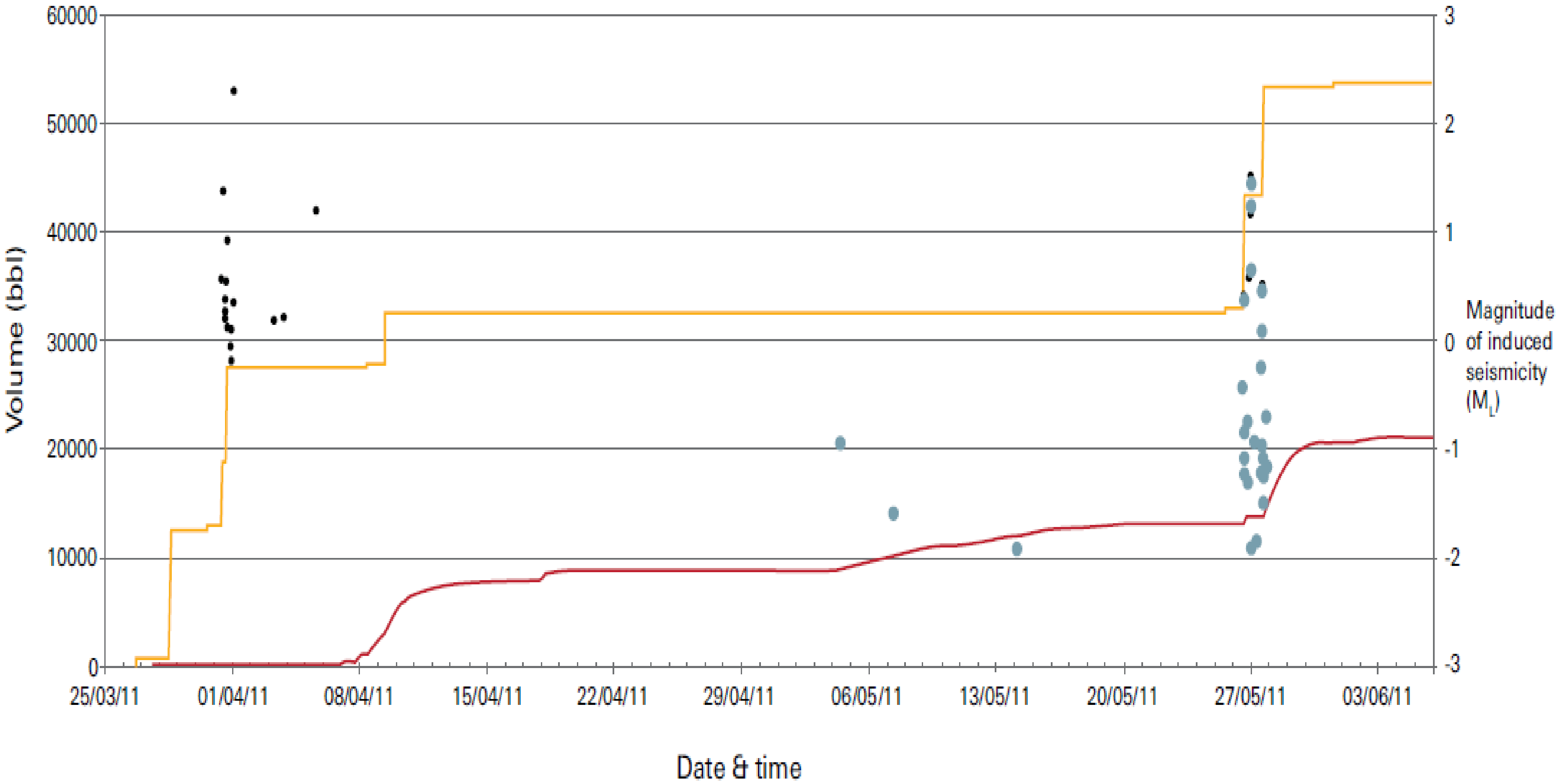
Induced Seismicity	
Risks	Potential for minor earth tremors. Multiple developments could increase the risk of events affecting other operations, e.g. affecting well integrity. Public perception of risks arising from induced seismicity affect public policy towards shale gas.
Causes	Well injection of hydraulic fracturing fluid reactivating pre-stressed faults.
Likelihood	Medium
Residual Risk	Unlikely to be significant, if control measures are implemented.

Natural seismicity (red) and coal mining-induced seismicity (green) in the UK from 1382 to 2012



Source: British Geological Survey

Preese Hall, Lancashire, UK



Amplitudes of Ground Vibrations

Item	Amplitude (mm s^{-1})
Threshold for major damage	60
Threshold for plaster cracking	50
600 m × 600 m vertical fracture initiated at 2.5 km depth in Carboniferous mudstone (M_W 3.6)	*c.* 50
Threshold for minor damage at Modified Mercalli Intensity V	34
Threshold for cosmetic damage	15
'Safe' limit	12.7
Slamming door	12.7
Upper limit for quarry blasting during the working day (allowable if unavoidable)	10
Jumping onto a wooden floor	8
Upper limit for quarry blasting during the working day (desirable)	6
Upper limit for quarry blasting during daytime outside the working day	4.5
Upper limit for quarry blasting at night	2
Lorry at a distance of *c.* 8 m	2
Threshold for felt effect at Modified Mercalli Intensity II	1
Walking on a wooden floor	0.8
DECC (2013*b*) limit for suspension of fracking (M_W=0.5 tensile earthquake) at 2.5 km depth	*c.* 0.4
Minimum threshold of perception for ground vibrations caused by blasting	0.25
Minimum threshold of perception for ground vibrations caused by road traffic	0.15

Control and Mitigation

Induced Seismicity
• Competent authorities compile regional maps of underground resources. • Operator to review available information on geology, structure (including faults) and in situ stresses in the vicinity of the proposed site to avoid hydraulically fracturing into, or close to, existing critically stressed faults. • Operator to conduct 2D seismic survey to identify faults and fractures. • Operator to engage with third parties (e.g. regulators, other operators, researchers) to ensure fully aware of any issues / proximity (e.g. to other underground activities). Sharing of information to ensure that all operators in a gas play are aware of risks and can therefore plan. • Require development of conceptual model of the zone before work commences covering geology, groundwater flows, pathways, natural microseismicity. Require ongoing development as data is collected through exploration. • Carry out modelling and risk based geomechanical assessments of proposed hydraulic fracturing with regard to faults (including maximum magnitude estimates). • Apply ground motion prediction models to assess the potential impact of induced earthquakes.

Control and Mitigation

Induced Seismicity

- Identify potential seismic receptors within a defined radius of the well site (5km) including: wells, infrastructure, special buildings, residential buildings and industrial/commercial buildings. Avoid high seismicity risk areas.
- Require minimum distance between hydraulic fracture pipes and geological strata containing aquifers (e.g. ~600m) and the surface (e.g. <600m depth requires special permit).
- Require appropriate well design, construction, testing and monitoring.
- Require smaller test preinjection prior to main operations to enable induced seismicity response to be assessed, followed by succession of injections over short duration of casing length.
- Monitor the fracture growth and direction during hydraulic fracturing using buried microseismic arrays to ensure hydraulic fractures / pollutants do not extend beyond the gas-producing formations and do not result in seismic events or damage to buildings/installations that could be the result of fracturing.

Control and Mitigation

Induced Seismicity
• Monitoring background induced and natural seismicity before, during and after hydraulic fracturing. • Implementation of the Traffic Light System (via the surface seismic monitoring array) and cessation of operation if induced seismic event exceeds 0.5ML. • Determine the presence and levels of methane in groundwater, including drinking water through sampling of shallow groundwater during wet and dry periods and/or borehole to sample deep groundwater and characterise the hydrological series.

Regulations

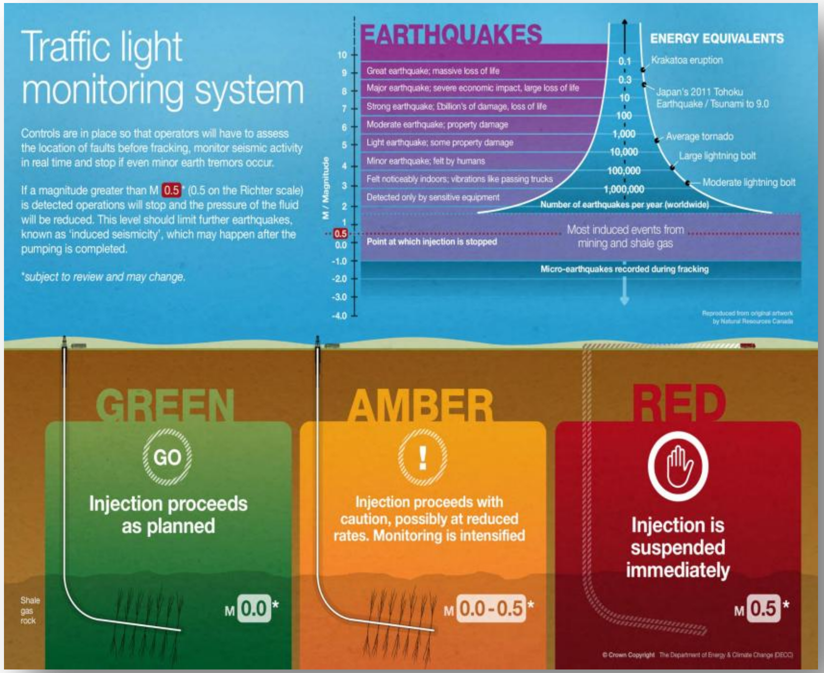
None, however, UK now (from Dec 2012) requires operators to

- conduct a prior review of information on seismic risks and the existence of faults;
- submit to DECC a hydraulic fracturing plan showing how any seismic risks are to be addressed;
- carry out seismic monitoring before, during and after hydraulic fracturing; and
- implement a “traffic light” system which will be used to identify unusual seismic activity requiring reassessment, or halting, of operations. In the context of the traffic lights:
  - ‘Green’ would mean magnitude of 0 ML which would mean injection could proceed as planned.
  - ‘Amber’ would mean a magnitude of between 0 to 0.5 ML would mean that injection could proceed with caution, possibly at reduced rates and that monitoring is intensified.
  - ‘Red’ is defined as a magnitude 0.5 ML or higher, where injection is suspended immediately and the pressure of fluid in the well is also reduced immediately.

Lessons Learned

Include:

- Importance of baseline and modelling to establish existing of pre-existing faults.
- Ongoing measurement and microseismic monitoring to determine fracture extent.
- Use of smaller test preinjections prior to main operations.
- Use of traffic light systems (although potential to revise thresholds).
- Independent inspection.



Emissions

Greenhouse Gas Emissions

What are the Risks and Effects?

Greenhouse Gas Emissions	
Risks	Increased greenhouse gas emissions as a result of exploration and production activities and shale gas consumption.
Causes	-Emissions released from construction activity, diesel generators, vehicle emissions, flowback and produced water (methane) -Fugitive emissions -Emissions associated with the consumption of shale gas
Likelihood	High
Residual Risk	Unlikely to be significant, if mitigation and control measures are implemented

Control and Mitigation

Construction activities

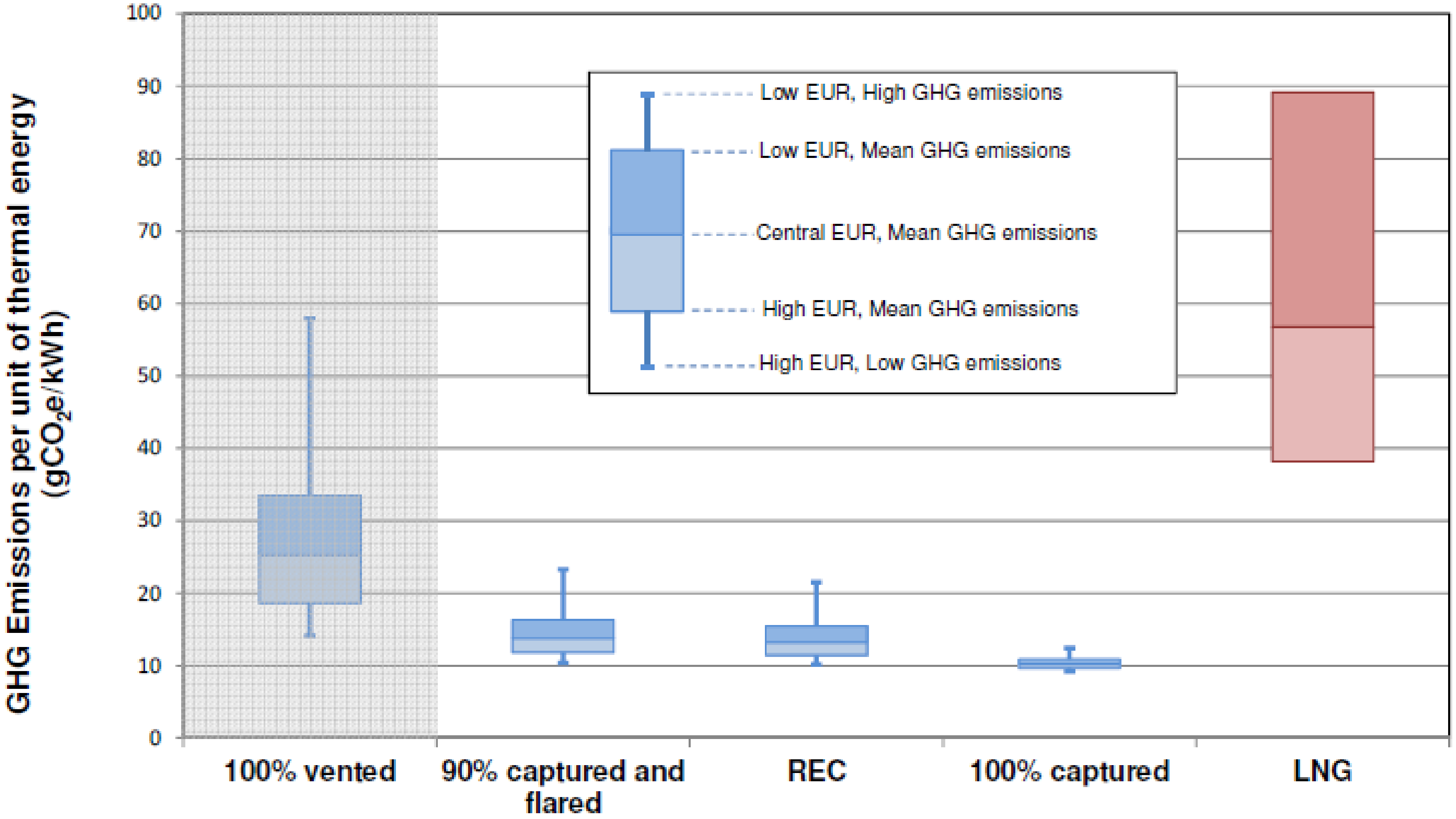
- GHG reduction measures may include, for example:
  - the use of construction materials with low embodied carbon;
  - measures to reduce private vehicle use for workers;
  - the use of low emission vehicles or HGVs conforming to the highest available standards for vehicle emissions;
  - the use of low emissions equipment and alternative energy sources;
  - use low emission power supply (i.e. LPG rather than diesel or use of grid electricity).
  - require lean burn and rich burn drilling rig engines.
  - development of a transport plan to reduce HGV traffic/congestion;
  - sourcing local materials, personnel, equipment and waste disposal;
  - connecting to water supplies and wastewater infrastructure;
  - provision for the transportation of materials and construction wastes by rail where practicable;
  - identifying opportunities for the on-site reuse, recycling and recovery of inert and non-hazardous waste; and
  - where possible, retaining equipment on-site.
- Require preparation and implementation of an Emissions Reduction Plan.

Control and Mitigation

Flowback Emissions

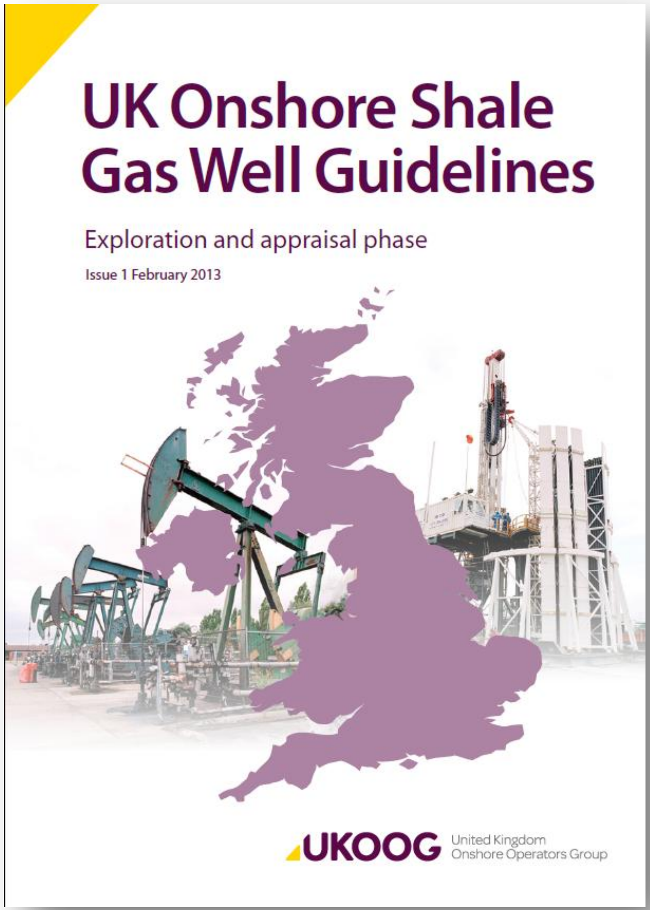
- Require preparation and implementation of an Emissions Reduction Plan based on the principle of as low a level as reasonably practicable (ALARP).
- Require reduced emission completions or green completions to eliminate gas venting and for capturing and cleaning for use of gas released from fracture fluid and produced water.
- Require enclosed completion systems be adopted to avoid venting from lagoons or tanks.
- Require flares or incinerators to reduce emissions from fracturing fluid at exploration stage (where not connected to gas network).
- Require monitoring of their sites to: (1) ensure early warning of unexpected leakages; and (2) obtain emissions estimates for regulators and government. This may include, for example, ambient air monitoring, hydrostatic pressure testing of pipework and equipment used to transport gas, regular seismic monitoring and monitoring of fracture propagation.

Life Cycle Analysis



Source: MacKay and Stone (2013)

Control and Mitigation



"Operators should plan and then implement controls in order to minimise all emissions. Operators should be committed to eliminating all unnecessary flaring and venting of gas and to implementing best practices from the early design stages of the development and by endeavouring to improve on these during the subsequent operational phases."

Regulations

Industrial Emissions Directive

- Permit required for flaring more than 10 tonnes of waste gas per day

UK includes:

- Environmental Protection Act
- Town and Country Planning (Environmental Impact Assessment) Regulations
- Environmental Permitting Regulations

Lessons Learned

Include:

- Importance of EIA and design
- Importance of Construction Environmental Management Plan and Environmental Management System
- Requirement of Emissions Reduction Plan based on the principle of as low a level as reasonably practicable (ALARP).
- Require reduced emission completions or green completions to eliminate gas venting and for capturing and cleaning for use of gas released from fracture fluid and produced water.
- Require enclosed completion systems be adopted to avoid venting from lagoons or tanks.
- Require flares or incinerators to reduce emissions from fracturing fluid at exploration stage (where not connected to gas network).
- Require emissions monitoring.

Concluding Remarks

Concluding thoughts

- Precautionary approach wise, using information from international studies, mirroring approach from EC; however:
  - Knowledge base is constantly improving, with more information and research becoming available
  - Regulatory frameworks in EU contain gaps
  - European measures remain unproven
  - Use of US information from historical activities may distort conclusions of studies as not representative of practice.
- Any revisions/amendments to Brazilian framework provides opportunity for:
  - Clear coherent and integrated approach which can be simpler than Europe and UK
  - Thresholds for water contamination and induced seismicity
  - Revision
  - Disclosure.
- For risks identified, proposed measures, appropriately employed can satisfactorily minimise risks; however, such measures also need to enjoy public confidence before application. Role, capacity and consistency of regulator and operators key to gaining the necessary public licence to operator.