EPR/AB3101MW

BAT Assessment of Artificial Lift Techniques

June 2019

BAT Assessment of Artificial Lift Techniques			
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Documents are reviewed as per proposed review date, or sooner if a significant change to the operation has taken place, to ensure relevance to the systems and process that they define.

Contents

Definitions

ALARP	As Low As Reasonably Practicable
BAT	Best Available Techniques
Barg	Gauge pressure
CNG	Compressed Natural Gas
EOR	Enhanced Oil Recovery
EPR	Environmental Permitting Regulations
LNG	Liquefied Natural Gas
mb	Millibar; Pressure equal to one thousandth (10-3) of a bar
MTWR	Minerals Technical Working Group
PSI	Pounds per square inch
PSIG	Gauge Pressure “Pounds per square inch”
REC	Reduced Emissions Completions

1.0 Introduction

Cuadrilla Bowland Ltd. has been granted an environmental permit (EPR/AB3101MW) under the Environmental Permitting (England and Wales) Regulations 2016 (as amended) (EPR) allowing the construction of the Preston New Road Exploration Site, followed by the drilling, hydraulic fracturing and flow testing of up to four wells.

Pre-operational condition 10 (PO10) of the site permit required additional operational details of the proposed onsite flares. PO10 was approved on 21/11/2018 (CARUP3431VF/0317879). In Cuadrilla's submission to satisfy the requirements of PO10, a scenario is outlined which includes the use of nitrogen gas during the early stages of well testing (known as well clean up) to artificially lighten the fluids within the wellbore, thereby encouraging upward flow towards the surface. This process, known as 'nitrogen lifting' is commonplace within the oil and gas sector. This report considers whether the use of nitrogen lifting is the best available technique (BAT) for the purposes of the EPR, and the resulting impacts on Cuadrilla's approved waste management techniques.

A BAT determination requires that an operator meets at least the best environmental outcomes that other operators are able to achieve using available techniques for the same activity. Nitrogen lifting is a common technique used by multiple alternative UK operators to achieve an artificial lift of a hydrocarbon well as part of a well clean up or following other well interventions. Nitrogen lifting has been utilised on multiple occasions in recent years, including at least five occasions during 2018.

2.0 Objective

The objective of the assessment is to demonstrate what the Best Available Technique ("BAT") is for an artificial lift after a well has been hydraulically fractured.

3.0 Scope

A range of artificial lift techniques has been assessed against a number of criteria including where relevant the following criteria specified in the Mining Waste Directive and the Industrial Emissions Directive:

1. the use of low-waste technology;

2. the use of less hazardous substances;

3. the furthering of recovery and recycling of substances generated and used in the process and of waste, where appropriate;

4. comparable processes, facilities or methods of operation which have been tried with success on an industrial scale;

5. technological advances and changes in scientific knowledge and understanding;

6. the nature, effects and volume of the emissions concerned;

7. the commissioning dates for new or existing installations;

8. the length of time needed to introduce the best available technique;

9. the consumption and nature of raw materials (including water) used in the process and their energy efficiency;

10. the need to prevent or reduce to a minimum the overall impact of the emissions on the environment and the risks to it;

11. the need to prevent accidents and to minimize the consequences for the environment;

12. the information published by public international organizations.

and in the case of the Mining Waste Directive information published under Article 16(2) of that directive as well as the consequences on Cuadrilla's approved waste management techniques, in order to determine BAT in this scenario.

The assessment of BAT does not include the artificial lift of hydrocarbons during long term production. The scope of this assessment is focused solely on a short term temporary artificial lift to aid the natural flow of natural gas during well clean-up for an exploration site. Production phase operations are therefore not included within the scope of this assessment.

4.0 Relevant policy, guidance and legislation

Best Available Techniques (BAT) Reference Document for the Management of Waste from Extractive Industries

The original reference document on Best Available Techniques (BAT) for the management of tailings and waste-rock in mining activities, abbreviated as MTWR BREF, was mainly drafted in the period 2001-2004 and published by the European Commission in January 2009 pursuant to Article 21(3) of Directive 2006/21/EC on the management of waste from extractive industries (the 'Directive'). The original BREF document was therefore prepared before the adoption of Directive 2006/21/EC and has now been superseded.

The Best Available Techniques Reference Document for the Management of Waste from Extractive Industries, in accordance with Directive 2006/21/EC, now abbreviated as MWEI BREF, originates from a review of the original MTWR BREF. The reviewed document presents updated data and information on the management of waste from extractive industries, including information on recommended BAT techniques, associated monitoring and developments in them. It was published by the European Commission in December 2018 pursuant to Article 21(3) of the Directive.

Environment Agency, Onshore Oil and Gas Sector Guidance

The guidance, original published in August 2016 and updated in May 2019, provides oil and gas companies, their service companies and consultants information to understand the environmental permits they need for onshore oil and gas operations in England, other permissions they may need from the Environment Agency and information about best available techniques that permit holders must use.

The specific relevance of this guidance to the current assessment is contained in section 7.0 Managing extractive waste and section 8.0 Flares at onshore oil and gas sites.

Environmental Permitting (England and Wales) Regulations 2016 (as amended)

Environmental permits are required for any activity defined as a 'regulated facility' in regulation 8. The specific activities which place regulatory requirements on the Preston New Road permit are Schedule 1 combustion activities and Schedule 20 mining waste operations.

Directive 2006/21/EC on the management of waste from extractive industries

Directive 2006/21/EC on the management of waste from extractive industries (hereinafter 'the Directive') aims to prevent or reduce as far as possible any adverse effects on the environment, in particular on water, air, soil, fauna and flora and the landscape, and any resultant risks to human health, brought about as a result of the management of waste from the extractive industries. The Directive covers the management of waste resulting directly from prospecting, extraction, treatment and storage of mineral resources and from quarrying.

Artificial lifting is a technique to be applied as part of our mining waste operations governed by the Directive. BAT is defined in the Directive by reference to the definition of that term in article 2(11) of the directive on integrated pollution prevention and control (Council Directive 96/61/EC of 24 September 1996) that preceded the Industrial Emissions Directive as follows:

'best available techniques' means the most effective and advanced stage in the development of activities and their methods of operation which indicates the practical suitability of particular techniques for providing in principle the basis for emission limit values and other permit conditions designed to prevent and, where that is not practicable, generally to reduce emissions and the impact on the environment as a whole:

(a) 'techniques' shall include both the technology used and the way in which the installation is designed, built, maintained, operated and decommissioned;

(b) 'available techniques' means those developed on a scale which allows implementation in the relevant industrial sector, under economically and technically viable conditions, taking into consideration the costs and advantages, whether or not the techniques are used or produced inside the Member State in question, as long as they are reasonably accessible to the operator;

(c) 'best' shall mean most effective in achieving a high general level of protection of the environment as a whole;

Under this definition the concept of BAT applies to the setting of emissions limits values only. The operation of the flares is also governed by the Industrial Emissions Directive where the definition of BAT was amended with effect in the UK from 2013 to also apply BAT to the setting of other permit conditions and to make BAT Conclusions contained with BREFs mandatory absent a derogation being granted.

Directive 2010/75/EY Industrial Emissions Directive (Integrated pollution prevention and control)

The Industrial Emissions Directive lays down rules on integrated prevention and control of pollution arising from industrial activities. It also lays down rules designed to prevent or, where that is not practicable, to reduce emissions into air, water and land and to prevent the generation of waste, in order to achieve a high level of protection of the environment taken as a whole. The IED aims to achieve a high level of protection of human health and the environment taken as a whole by reducing industrial emissions across the EU, in particular through better application of Best Available Techniques (BAT).

Definition of BAT

Artificial lifting is a technique to be applied as part of our mining waste operations governed by the Directive. BAT is defined in the Directive by reference to the definition of that term in the directive on integrated pollution prevention and control that preceded the Industrial Emissions Directive as follows:

Below is an extract from Article 3, Directive 2010/75/EU Industrial Emissions (integrated pollution prevention and control) providing the applicable definition of BAT:

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The Health and Safety at Work etc, Act 1974

The Act imposes a duty on employers towards their employees to ensure, so far as is reasonably practicable, their health, safety and welfare and in particular:

(a) the provision and maintenance of plant and systems of work that are, so far as is reasonably practicable, safe and without risks to health;

(b) arrangements for ensuring, so far as is reasonably practicable, safety and absence of risks to health in connection with the use, handling, storage and transport of articles and substances;

(c) the provision of such information, instruction, training and supervision as is necessary to ensure, so far as is reasonably practicable, the health and safety at work of his employees;

(d) so far as is reasonably practicable as regards any place of work under the employer's control, the maintenance of it in a condition that is safe and without risks to health and the provision and maintenance of means of access to and egress from it that are safe and without such risks;

(e) the provision and maintenance of a working environment for his employees that is, so far as is reasonably practicable, safe, without risks to health, and adequate as regards facilities and arrangements for their welfare at work.

The Dangerous Substances and Explosives Atmospheres Regulations 2002 (DSEAR)

An employer's duty under DSEAR involves ensuring that risk is either eliminated or reduced so far as is reasonably practicable, which includes as priority wherever reasonably practicable selecting an alternative to a dangerous substance to eliminate or reduce the risk, and if it is not reasonably practicable to do so, applying measures that are consistent with the employer's risk assessment and that are appropriate to the nature of the activity or operation to control the risks and to mitigate the detrimental effects of a fire or explosion or the other harmful physical effects arising from use of the dangerous substance.

Borehole Sites and Operations Regulations 1995/2038

A borehole operator is under a duty in accordance with regulation and paragraph 9 of Schedule 2 where there is a risk of explosion, to take all necessary measures with a view to:

(a) preventing the occurrence and accumulation of explosive atmospheres; and

(b) preventing the ignition of explosive atmospheres.

Environment Agency, Control of landfill gas containing low concentrations of methane

An Environment Agency Science report which examines scenarios for landfill sites provides that where methane content of the landfill gas falls below a certain level it cannot be used to generate electricity and the gas will need to be flared. When the methane content falls again, there is simply not enough methane to keep a flare alight. At this point the gas is known as low calorific landfill gas and it is currently vented untreated into the atmosphere. The reports provides a reference on technology available on the market for the flaring of low methane concentration landfill gases.

Hydrocarbon BREF Best Available Techniques Guidance Document on upstream hydrocarbon exploration and production

The Guidance Document has been developed based on information provided by a Technical Working Group (TWG) in response to data collection questionnaires; extensive comments on drafts of the Guidance Document; as well as additional data provided by TWG members and collected by the project team. The main driver behind the Guidance Document is to improve protection of the environment. Although the hydrocarbons industry has operated for many years with a range of far reaching regulations, standards and guidance in this regard, this Guidance Document attempts to unify these for the European context in terms of practices and intent.

BAT in the wider context

In setting permit conditions that apply BAT, the Environment Agency is required to ensure that the objectives of the relevant directives are achieved.

In this regard, the Mining Waste Directive requires that any adverse effects on the environment and human health are prevented or reduced as far as possible through the use of BAT, without prescribing the use of any technique or specific technology and taking into account the technical characteristics of the waste facility, its geographical location and the local environmental conditions.

Article 11(g) of the Industrial Emissions Directive sets as a one amongst several principles of which the need to ensure that BAT is applied is one, the principle that the necessary measures must be taken to prevent accidents and limit their consequences.

The Environment Agency is therefore required to balance the needs of minimizing risks to human health and reducing the risk of accidents occurring against the need for environmental protection, where there is any conflict between the two.

Under the Industrial Emissions Directive, the Environment Agency is free to select an alternative BAT to those described in relevant BAT Conclusions provided it gives special consideration to the criteria listed in Annex III (as set out within the Scope of this assessment section above); and complies with Article 15 of the directive. However if the adopted BAT conclusions do not contain emission levels associated with BAT, the Environment Agency must ensure that the technique selected by it as BAT ensures a level of environmental protection that is equivalent to (rather than identical to) those described in the BAT conclusions.

Where an activity is not covered by an Industrial Emissions Directive BAT conclusion or where those conclusions do not address all the potential environmental effects of the activity or process, the Environment Agency must consult with the operator first and then set permit conditions on the basis of the BAT that the Environment Agency determines by giving special consideration to the Annex III criteria.

5.0 Assessment of BAT

This assessment will consider a range of techniques to achieve an appropriate balance between the environmental benefits and the costs to implement them.

The BAT assessment will:

1. Outline potential available options to conduct an artificial lift;
2. Assess the viability and availability of each option;
3. Assess the environmental impact of each available option;
4. Evaluate the costs of each available option
5. Present a safety risk assessment of the options for use of different gases; and
6. Conclude a preference option in accordance with BAT conclusions.

6.0 Well test completion design and clean up phase

Depending on the well architecture, the well completion will be designed to allow for two scenarios; natural flow and artificial lift. Generically speaking, a well is completed with a series of conductor pipes and accessories installed. The basic components of the well include casing strings with the space between the casing strings called the annulus. A packer may seal the annulus just above the production zone. The casing which has been perforated, or in Cuadrilla's design, a sliding sleeve assembly, allows gas and liquids to enter into the wellbore or the tubing string when operated.

Cuadrilla's well test downhole completion is designed to have the smallest diameter tubing possible. This is done to maximise the velocity of the fluid flow up the well and maximise the possibility of the well flowing naturally to deliver a representative well test.

The completion size is typically 2 3/8" OD pipe, which is the minimum size dictated by the requirement to utilise wireline retrievable plugs inside the tubing as the string is being run, so that well control barriers can be maintained. The OD of these plugs is 1.5". Smaller plugs are not available, and hence the minimum tubing size is 2 3/8" OD. The 2 3/8" string has been specifically procured for the purposes of the welltest. Consequently, due to the well design and sizing, mechanical lifts are not available for this well design.

Following the stimulation phase, a well needs to be "cleaned up" in order to establish self-sustained flow. Well clean ups that involve hydraulic fracturing result in a higher rate of liquid flowback than most conventional well completions, due to the large quantities of water and proppant (mainly sand) used to fracture lower permeability reservoirs. This high-rate flowback is generally composed of a mixture of fracturing fluids with reservoir gas and liquids. For most hydraulically fractured wells, it takes from one day to several weeks to perform a well clean up, during which the flowback mixture is returned to the surface and handled via a separator which separates gases and liquids. This design is known as a green completion or Reduce Emissions Completions (RECs) and is acknowledged as BAT in the Mining Waste from Extractive Industry BREF document (BATc 51) for exploration and production facilities. It should be noted that the current design of the Preston New Road does not have a connection to the gas grid as the site is currently in the exploration phase, so gas is flared. A BAT assessment for the use of the flare in these circumstances has been completed previously. As well as being optimized for a self-sustained flow well test, the selected tubing size also reduces to a minimum the duration of the well clean-up phase.

6.1 Natural flow

Under ideal circumstances, a well will 'self-lift' using only the bottomhole pressure from the surrounding formation fluids. Where this does not occur naturally, it may be possible in certain circumstances to shut-in a well for period of time (this may last between several hours to several days, but cannot be accurately or confidently predicted) to allow bottomhole pressure to build. Where the buildup of pressure is sufficient, upon reopening the well, the built up pressure is sufficient to lift the remaining liquids to surface after which no additional lift is required. This option, where possible requires no further addition of material into the well, and generates no additional waste streams or quantities beyond those already accounted for.

This option is preferable wherever possible on both environmental and economic grounds, and will be attempted first on any wells at the site, however, its use is limited to those situations where sufficient formation pressure naturally exists to overcome the weight of the well control flowback fluids and present. In the case of the PNR1z well at the Preston New Road site, this technique was not viable to initiate the flow of hydrocarbons from the target formations to the surface. For this reason, this technique cannot be considered to have been BAT in those circumstances. Natural lift will be attempted on all future wells at the site, but as it cannot be relied upon to be successful, therefore it cannot be considered BAT.

6.2 Artificial Lift

Artificial lifts systems are designed to help natural reservoir energy lift the formation fluids to the surface. There are two basic types of artificial lift; mechanical and gas-based. Section 8.0 below details the available artificial lift options. The basic premise of an artificial lift is to remove the static column of liquid which creates hydrostatic pressure preventing the flow of natural gas to surface. In the case of hydraulic fracturing, the liquid column is predominantly created by the return of the fracturing fluid, however this can also be water contained within the formation.

The duration of an artificial lift can vary depending on the well programme objective and an individual well's performance. The well programme objective for this assessment focuses on a temporary short term lift to initiate self-sustaining natural gas flow to surface at the commencement of well testing. The duration of the artificial lift is confined between a few days to several weeks. The phase is not intended or designed to be permanent in duration. The objective is to lift and unload the fluid column out of the well as quickly as possible to initiate natural gas flow to the surface. The decision to suspend or stop an artificial lift is governed by the ability of the well to unload the fluids using its own natural formation pressure and being able to self-sustain the flow of liquids to the surface. The duration of an artificial lift well clean-up is a function of many reservoir properties, but based on experience on PNR-1z it is estimated that a clean-up period of up to one month will be sufficient to enable self-sustained flow.

For background, a gas lift is different to gas injection. Gas injection involves a dedicated wellbore to inject gas into the formation to enhance oil recovery for long term production. The design and well objectives are fundamentally different for a gas injection so cannot be compared to a gas lift in this scenario.

7.0 Available techniques

Mechanical techniques

A number of mechanical techniques exist which can be used to lift a well to initiate upward flow of hydrocarbons within a well following a completion or well intervention. Certain techniques have operational constraints which can restrict their use. This section outlines a number of general techniques for successfully lifting a well, and identifies those which may be operationally suitable at the Preston New Road site.

Swabbing

Swabbing involves reducing bottomhole pressure within a well by pulling wireline tools or rubber-cupped seals upwards from a well's base. The effect of physically lifting the column of well fluids in this way reduces the hydrostatic pressure in the wellbore, this therefore increases the pressure differential between the reservoir and the wellbore which in turn encourages the inflow of formation fluids into the well.

This option, where possible, requires the addition of no further material into the well (beyond the tool itself), and generates no additional waste streams or quantities beyond those already accounted for in the initial drilling and completion of the well.

This technique has been used previously at Cuadrilla Preese Hall site, however its application is preferred to vertical or near-vertical well sections. As such, it is not primarily suited for use as a lifting technique in the extended lateral well sections (i.e. the wireline is poorly suited within deviated wellbore sections) at the Preston New Road site.

The objective of swabbing is to reduce bottomhole pressure and create an underbalanced pressure to allow fluids to enter into the well. A sudden drop in hydrostatic pressure can result in a large ingress of formation fluid which induces a kick scenario (sudden influx of formation pressure) which can be unpredictable. The process of inducing kicks into the well with equipment at surface being pulled out of the hole will increase the safety risk to site operatives working near the wellhead at the same time. The returning gas will be vented to safely control the kick pressure. A further constraint of this techniques is that it can induce sand from the formation into the wellbore which can both reduce well productivity and cause additional well operation and maintenance problems. For this reason, we do not consider this technique to be BAT for Preston New Road on account of safety concerns, risk of compromising well productivity and its potential lack of achieving a successful lift in a lateral well. Therefore, this technique is not considered further in this report.

Downhole pump

Downhole pumping involves the installation of a pump (typically electrically powered from the surface) mechanism at the base of the wellbore to mechanically lift fluids within the wellbore to surface. The use of such a pump allows the intermittent or continuous pumping of bottomhole fluids in order to reduce bottomhole pressure and thereby encourage the inflow of formation fluids, including natural gas, from the surrounding formation.

Downhole pumping can be used in either vertical, or less effectively, in horizontal well sections. However, the installation of a downhole pump requires consideration during well design, and cannot be installed retrospectively. Downhole pumping is principally used as long term technique in production scenarios rather than during exploration activities, as at Preston New Road. A further limitation of using downhole pumping in the context of the Preston New Road site is that the presence of sand (or similar solids) can cause operational difficulties (such as clogging and abrasion) for mechanical (and similar) pump types, and present an increased risk of malfunction or failure. Such malfunctions typically require additional downhole interventions (with a corresponding increase in surface facilities and environmental impacts) to rectify. As the injection of large quantities of sand are integral to the planned operations at the site, we consider the use of mechanical (and similar) downhole pumping techniques are not BAT for the proposed operations at this site. As this technique cannot be retrofitted within the existing well design, and is not compatible with an inherent aspect of the site operations (the use of proppant), it is not considered further in this report.

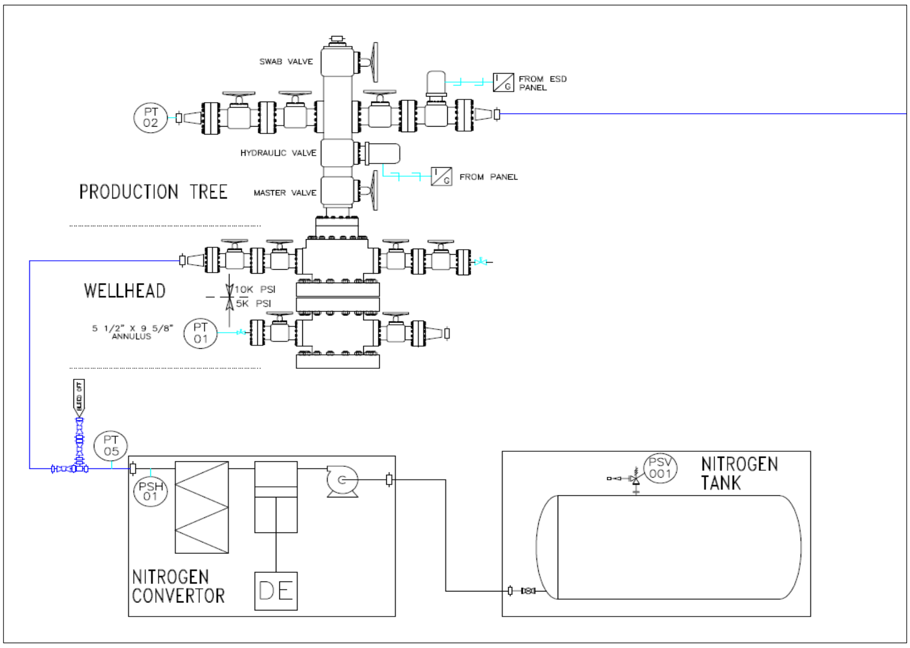
Rod pumping

A technique used in a number of industries including the water industry, rod pumping units, utilize an up and down reciprocating motion containing a string of sucker rods to pump water to the surface. Rod pumping can be used in either vertical, or less effectively for horizontal well sections resulting in the wellbore being under lifted. Rod pumping has disadvantages for horizontal gas wells; for example the effects of gas interference resulting in gas displacing fluid entering the pump resulting in less than optimal stroke performance. Furthermore, gas interference may damage the rod system when the pump travels faster than liquid in the pump barrel. In addition to these disadvantages rod pumping is not compatible for this well configuration or stage of well completion. Rod pumping is principally used for long term production rather than short term unloading of liquid to allow natural formation pressure to self-sustain flow. As this technique is not applicable to this phase of operation, well design or well objective we do not consider this technique is BAT, and it is therefore not considered further in this report.

Gas lift techniques

The use of a gas lift in terms of its versatility to be used for almost every type of well cannot be matched by other mechanical methods of artificial lift if adequate injection gas pressure and volume are available. Deviated wells that produce sand are the best candidates for gas lift techniques when an artificial lift is required. Gas lift devices are simple in design, with few moving parts, without the risk of returning sand laden fluid damaging or blocking mechanical parts e.g. pumps, rods, valves etc. Subsurface gas lift equipment is relatively inexpensive and readily available in the UK. Surface equipment requires little maintenance and limited space for installation. An example P&ID drawing below details a gas lift surface set up for an exploration site.

Drawing 1: Example drawing of surface gas lift set up.



The primary engineering considerations in the selection of a gas lift are the availability of gas and the ability to pressurise the gas at surface to lift the fluid from the well.

As the site does not currently have a pipeline to transport gas to the surface facilities, gas has to be tankered to site. Liquefied nitrogen (<10 bar) is the preferred method of transportation as it takes up significantly less volume than compressed gas. Liquefied natural gas takes up 600 times less space than the gas in comparison to compressed natural gas which takes up 200 times less space. The tankers offload the gas to a storage tank. The nitrogen is then transferred to a compressor pump/convertor for subsequent pressurised injection into the wellbore. Compressors must be designed to allow for the output (flow rate) to be adjusted to reflect injection rates to optimally balance the demand for gas into the well. Gas is injected into the completion tubing annulus or by using coil tubing to create an 'inner annulus'.

The volume of gas required for a lift varies depending on the reservoir and well characteristics. Therefore, operations must have the flexibility of pumping pressurised gas at several hundred cubic meters to several hundred thousand cubic meters of gas, over a continuous basis for period of between several days to several weeks.

Gas is pumped in accordance with the wellhead pressure to lift the fluid column successfully. Wellhead pressure is fundamental to achieving a gas lift as an indicator of the flowing bottom-hole pressure. Each well will have its own specific wellhead pressure, however for Preston New Road, the approximate wellhead pressure is equivalent to ~200 barg (3000 psig) at surface. For a gas lift to be successful, the surface equipment needs to be designed to reflect these key design parameters (pressure, compressor adjustment and reliable supply of gas).

Safety and environmental considerations are key criteria in assessing options. Wellhead and wellbore architecture require safety hazards to be identified and risk assessed as part of UK regulatory requirements. The use of pressurised gases at surface cannot be considered in isolation of environmental considerations. The selection of gas and safety barriers need to demonstrate adherence to the ALARP (as low as reasonably practicable) principle of health and safety regulations.

The availability of different gas types will be reviewed as part of this assessment, however standard oilfield practice is to utilise nitrogen, including on at least five occasions by UK onshore operators during 2018.

Nitrogen

Nitrogen lifting is routinely practiced in a wide range of oil and gas settings and scenarios for the lifting of a well fluid following completion or following well workovers or other downhole interventions. Nitrogen is preferred for such applications as it is lighter than air, chemically inert, readily available, non-hazardous and non-polluting.

The use of nitrogen also offers significant safety advantages over alternative gas-based lifting techniques as it is both non-combustible and has an asphyxiating property which reduces the potential for ignition or combustion of flammable materials.

As the principal constituent of air, nitrogen is naturally abundant and readily available. The equipment required to pressurise nitrogen to the requisite levels is readily available.

Nitrogen lifting has been shown to be effective at clearing wellbore liquids, and initiating hydrocarbon flow in many scenarios and can be applied to the Preston New Road site.

Nitrogen offers a number of advantages over alternative gas-based lifting techniques, which include:

- pumping equipment is readily available for industrial use;
- abundance (being the principal constituent of air) and cost effective;
- lighter than air (thereby offering additional buoyancy within the well);
- non-polluting (as nitrogen is inert and already ubiquitous);
- offers safety advantages over certain available alternatives (as it is non-combustible);
- non-corrosive; and
- compressibility of nitrogen and its temperature changes are predictable for downhole injection.

Gas-based lifting techniques, including the use of nitrogen, offer further operational flexibility in that they can be used in vertical and lateral well sections alike, and require no additional downhole equipment. As nitrogen lifting is a viable technique, it is considered the base case for this BAT assessment against which all other techniques will be judged.

CNG and LNG

Lighter than air both CNG and LNG will provide good buoyancy to lift the liquids. The nature of compressibility and its temperature changes are also predictable. The miscible mixing of natural gas with formation gas means that they will return to the surface in the form of a gas mixture which will be combusted at the flare.

Whilst the properties of CNG and LNG could achieve a liquid lift in principle, the wider safety implications of their use must be considered. The UK health and safety regulatory regime requires that all safety risks are reduced in line with the ALARP principle. The exploration site and wellbore are designed and constructed for natural gas to flow to the surface via production tubing. It is not designed to inject a combustible and explosive gas down the annulus or circulating system. A short term gas lift risk assessment involving the use of a combustible and explosive material fail to satisfy the ALARP principle when weighed against the safe and proven use of inert gas (e.g. nitrogen), (See Section 10). A safety risk assessment of using combustible and explosive gases in an artificial lift system is detailed in Appendix A. Considerable redesign of the wellhead configuration, gas lift valves (emergency shut down systems, backpressure valves, and check valves) and wellbore design would be required to manage the risk of injecting a combustible and explosive gas.

Having explored options from major UK suppliers the rental availability of CNG and LNG is considerably limited in comparison to off the shelf liquefied nitrogen. CNG can be compressed to levels up to 230 barg however when unloaded directly from the transport vessel the pressure of the compressed natural gas reduces significantly when transferred. As a result a standard delivery of CNG would only operate at the upper pressure rate approx. $15m^3$ and then substantial reduce as unloaded. Therefore to store CNG at the required wellhead pressure would require substantial on site storage of compressed natural gas increasing the risk profile of the site. LNG is delivered at low pressure and transferred to tank storage at site.

To pressurise LNG and CNG to well head pressure (200 barg) a natural gas convertor/compressor will be required, which from market review (with a major contractor and supplier) of rental convertors/ compressors are not available in the UK or Europe for short term application e.g. a gas lift.

Therefore CNG and LNG are not considered available techniques due to (i) the lack of a market for short term high pressure compressors and convertors and (ii) the inferior safety considerations to nitrogen gas.

Carbon dioxide

Carbon dioxide (CO2) is a complex gas to manage with a requirement to use specialist equipment. Lighter than air, carbon dioxide provides a good source of buoyancy to lift fluids and as a non-flammable substance provides safety advantages. However pumping carbon dioxide downhole can cause corrosion of casing reducing wellbore integrity as well as compressor leaks at the surface causing fugitive emissions. CO2 can be pumped in liquefied form but will need to remain under pressure due to the risk of CO2 solid ice formation causing blockage in lines and the wellbore.

Another disadvantage of carbon dioxide is that when pumped at pressure as a gas, CO2 tends to start vaporizing at 900 to 1000 psig and therefore cannot lift the fluid. The wellhead pressure at Preston New Road is approximately 3000psig, the vapourisation of the gas adds an additional complication to using carbon dioxide as a lift gas. As a consequence carbon dioxide lifts is an inferior option due to:

- Corrosion risk which will elevate the risk of compromising well integrity and surface equipment due to CO2 mixing with downhole liquids forming acidic well fluids;
- Compromised ability to pump high pressure gas and ability to unload a well (due to vapourisation at comparatively low pressure);
- Potential for leaks of carbon dioxide at surface from compressor stations, loading and unloading procedures; and
- The need to maintain pressure of liquefied CO2 within a narrow margin in order to avoid causing solid ice blocks in lines and wellbore creating pressure points and preventing flow of fluids.

With the significant disadvantages compared to other gases, carbon dioxide is not considered as a technically viable option and is therefore not an available technique.

Air

Air lifting was established in the 1920s but has now been largely replaced by alternative gas options that have become more widely available. Alternative gases, which are lighter than air, provide a superior performance and lessen the fire and explosion hazards to people and the surface equipment and to well integrity if an explosion occurs within the wellbore created by air when exposed to combustible materials, as well as causing damage to equipment through oxidation. As a consequence air lifts are an technically inferior option due to:

- Air specific gravity is higher than nitrogen and is less effective to lift column of well fluid due to its lower relative buoyancy.
- Gas lift technology has advanced since it was originally conceived in oilfield practice with pure nitrogen now commercially available.
- UK safety assessment does not classify the use of air as ALARP due to alternative inert gas options being available;
- Potential combustible mix with downhole fluids and oxidation risk causing corrosion; and
- The performance is inferior to a nitrogen lift which is more buoyant in fluids.

Air is not considered further as an available technique due to the safety and performance standards being inferior to alternative gases.

Hydrogen and oxygen

From a review of available literature we have not found any examples of either of these gases being used in gas lift operations for onshore oil and gas exploration. Hydrogen and oxygen are not available techniques due to the explosive and potentially corrosive nature and lack of application to this commercial operation. A further disadvantage is the need to design and manage the potential embrittlement of surface and sub surface pipework/ wellbore integrity due to hydrogen.

As with CNG and LNG, considerable redesign of the wellhead configuration, gas lift valves (emergency shut down systems, backpressure valves, and check valves) and wellbore design would be required to manage the risk of injecting hydrogen or oxygen since they are combustible and explosive.

Due to the elevated risks associated with the corrosive and combustible and explosive properties and their incompatibility for use with the wellbore and surface architecture, neither of these gases are considered viable.

Natural gas from an alternative well

There is potential to utilise natural gas from an existing adjacent producing wellbore. This scenario is not applicable to the exploration phase but may be viable in a future production scenario. Applicability of this technique requires reliable and known data including gas inventories and wellhead pressure to enable verified wellhead design and wellbore architecture.

A number of wells will be required to justify the large financial investment in a compressors (circa >£1M) to lift wells (if at all) and surface design would need to be planned for this technique to be viable and cost effective. This design would be necessary in order to carry out a suitable and sufficient risk assessment to allow Cuadrilla to comply with health and safety regulation.

As an existing producing wellbore or known characteristics of the exploration phases is not currently available, or the known flow rates and pressures from varying well depths located in different horizons of the Bowland formation are unknown, the option is not viable until further geological data provides greater certainty. For the current phase of operations this scenario is not applicable and is not considered further for this assessment.

8.0 Environmental impacts of available techniques

The environmental impacts of the available techniques have been considered. Mechanical techniques are not available so are not considered further.

Gas lifting

The environmental aspects (positive or negative impact on the environment) are outlined below in the table to appraise each option. The majority of environmental impacts on the environment are insignificant. However, where an environmental impact requires further analysis, to demonstrate that the risk is insignificant, further assessment has been used to quantify the level of impact.

Table 1.0 summary table of environmental aspects

Gas	Environmental aspects
Nitrogen	• Compression leaks from surface are not considered a fugitive emission. • Liquefied and easily transported to site keeping HGV traffic movements to a minimum e.g. PNR1z required approx. 10 HGV deliveries. • Inability to combust at flare when mixed with low concentrations of formation gas leading to potential venting at flares. • Inert to groundwater and would not corrode wellbore and surface line integrity.
CNG/ LNG	• Compressed gas requires high frequency of HGV deliveries to site. Likely to need double the amount HGV's than liquefied gases (based on the assumption of onsite compressor being available). • Liquefied and easily transported to site keeping HGV traffic movements to a minimum. Similar quantity to N2 delivery number. • Ability to flare rather than vent at surface leading to carbon dioxide release from flare. • Regasification and compressor leaks leading to fugitive emissions at surface.
CO_2	• Regasification and compressor leaks leading to fugitive emissions at surface. • Potential inability to combust at flare when mixed with low concentrations of formation gas leading to potential venting at flares. • Liquefied and easily transported to site keeping HGV traffic movements to a minimum. Similar quantity to N2 delivery number. • Corrosive risk downhole leading to potential well integrity failure and groundwater contamination risk
Air	• Explosive risk downhole creating underground blowout and well integrity failure leading to groundwater contamination risk. • No pollution risk to groundwater
Oxygen	• Explosive risk downhole creating underground blowout and well integrity failure leading to groundwater contamination risk. • Explosive risk at surface and flare system leading to uncontrolled release of emissions from fire. • No pollution risk to groundwater
Hydrogen	• Explosive at surface and corrosive risk downhole creating underground blowout and well integrity failure leading to groundwater contamination risk • No pollution risk to groundwater

Impacts on gas flaring and venting

There is no commonly accepted BAT for flaring systems at onshore oil and gas operations (for example, a BREF document). The current flaring arrangements for Preston New Road have been assessed as

BAT for the combustion of waste natural gas. This assessment considers further the use of the flares for managing a nitrogen/methane mix.

There are two flares located at site which have been previously assessed as BAT by the Environment Agency. The design of the flares are compliant with the Environment Agency's published interpretation of BAT as detailed in the onshore oil and gas sector guidance, as follows:

The Environment Agency takes a precautionary approach. They consider enclosed flares to generally provide the best environmental performance for incinerating waste gases.

An enclosed flare is characterised by the following features:

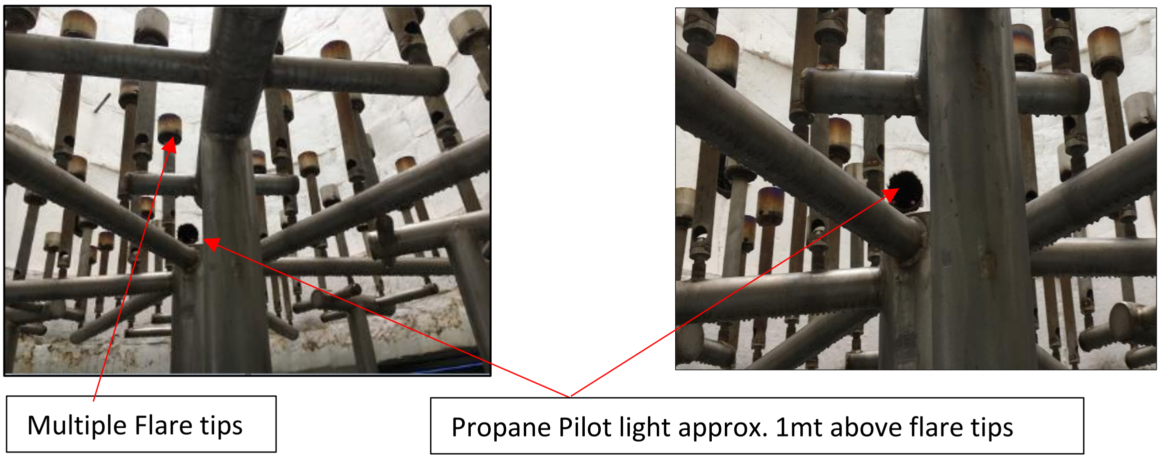
•the burners are designed to operate within an enclosure

•the enclosure is thermally insulated

•there is a mechanism to control the combustion air feed rate to optimize combustion

The setup of the flares utilises two pilot lights which are lit before any gas enters the flare by an independent propane system. The independent pilot lights are situated above the flare tips providing an ignition source for the natural gas exiting the flare tips, to mix and subsequently combust. See photo 1 site photos and arrangements.

Photo 1: Flare tips and location of pilot light. Pilot light located above the flare tips



As gas leaves the separator it flows into a single flare flow line. The flare flow line diverts to one of four flow lines depending on the pressure/flow conditions occurring. Each flow line is configured to manage either low flow, low pressure, high flow or high pressure. The flares regulate the flow rate to the flare tips via a series of valves to allow for low or high pressure/ low or high flow combustion (up to 2500m^3 per hour per flare). Each flare is designed with a 10: 1 turndown ratio, meaning that flares are designed to operate at down to 10% of their maximum combustion heat release load.

In a low flow, low pressure scenario, as experienced during a nitrogen lift, pressure and flow rates are variable, natural gas may flow between 0-600m^3 per hour (flow is 0m^3 during slug flow as the well reduces flow and then surges in with liquid). The pressure is aligned with the flare system variable pressure envelop.

As the gas mixture exits the flare tips it passes through the pilot light flame. When a combustible source of gas passes through the flame the flare ignites the gas and combustion is achieved. Automatically adjusting louvres at the base of the flare allow additional air to be introduced into the flare system to aid and optimize combustion.

In a nitrogen lift scenario, the gas mixture exiting the flare's burner tips may be incombustible due to the suppressing effect of high concentrations of nitrogen at the point of intended ignition. By design, a minimum concentration of 30% v/v methane is required in the gas stream. During PNR-1z operations, tests were carried out at up to 30% v/v methane, and this was demonstrated to be incombustible. Based on this previous experience and in consultation with the flare manufacturer, we consider the gas mixture is highly likely to combust when methane reaches between 30%vv/v - 98%v/v. Also in conjunction with our flare manufacturer, we have undertaken a review of the existing flare design and the residence and mixing time of gas in the flare. This review with the flare manufacturer identified no available modifications or improvements which can overcome the blanketing effect of nitrogen in this scenario.

Due to the quantity and flow rates of nitrogen, the inlet mixture of a dominated inert gas can lead to low temperature or incomplete combustion at the surface flare system. As outlined in Pre-operational condition 10; 'i*f nitrogen or other inert gases are fed into the flowlines before the flare additional propane may be added to help support combustion until ignition is achieved. This does not guarantee full combustion of natural gas so some gas maybe cold vented*.'

The addition of propane while methane concentrations remain below 30% v/v have empirically been observed not to ignite the flare. For this reason, we do not plan to add support fuel after five minutes when methane concentrations are < 20% v/v, to avoid unnecessarily venting of propane (see section 13 for justification). However, when monitoring indicates a consistent concentration of above 20% v/v, support fuel tests will be conducted.

We have undertaken a review of various additional sources of information, including Environment Agency science report; Control of landfill gas containing low concentrations of methane – SC030305/SR2 March 2009. This provides useful information on combustion techniques for low calorific value landfill gases, but does not provide a comparative reference relevant to a well clean-up scenarios in an oil and gas exploration setting.

Landfill gas composition is markedly different to that of the gas composition encountered during a well completion at Preston New Road. Returns to the surface during nitrogen lifting consist of nitrogen and lower concentrations of methane with no oxygen in the flow lines. Empirical evidence from the testing of PNR1z well demonstrated that a mixture of 30%:70% methane to nitrogen mixture did not combust, even with the addition of propane as a support fuel.

It is recognised from the science report that due to the costs of purchasing and installing a low calorific flare it is important that the system is operational over several years to make it economically viable. A nitrogen lift could last as little as one day to a maximum of several weeks. As such, it is not viable to invest in new equipment for so short a period. It is not considered likely that such new equipment would be any more effective at achieving combustion in this scenario relative to the currently installed enclosed ground flares, which themselves have been accepted as BAT. Furthermore, the report concludes that low calorific systems are deployed at sites where there is a comparatively low level of gas production, typically requiring forced extraction (pumping). This is the opposite scenario for a nitrogen lifting scenario which is actively trying to encourage large quantities of natural gas to flow from a formation.

Environment impacts conclusion

Due to the inert, non-hazardous and non-polluting nature of nitrogen, it offers significant environmental benefits over alternative gas-based lifting techniques. These include not posing any risk to wellbore integrity and subsequent groundwater contamination risk or explosive risk which could compromise well and surface integrity. However consideration must be given to the quantification of potential venting arising from a nitrogen lift at the flare due to its incombustible properties and the subsequent global warming potential of any emitted natural gas. Details of this are outlined in section 9.0.

The following table provides a summary assessment of global warming potential of the Preston New Road flares venting gas to atmosphere compared to flaring.

Table 2: Environmental impacts of venting and flaring scenarios

PNR 1z Emissions estimates	Greenhouse gas emissions (tCo2e)
2.7t (lower) venting	75.6
2.7t (lower) venting with support fuel	77.8
2.7t (lower) flaring	4.1 (plus support/pilot fuel)
6.8t (upper) venting	190.4
6.8t (upper) venting with support fuel	192.6
6.8t (upper) flaring	10.5 (plus support/pilot fuel)

For comparative purposes, the energy sector in the UK emitted 393,300,000 tCO2e in 2016, the most recent year for which final data is available. (UK Greenhouse Gas Inventory, 1990 to 2016, BEIS (2018))

Alternative gas-based lifting techniques pose significant safety risks to the integrity of the wellbore and surface facilities. Furthermore, the use of LNG and CNG fugitive emissions are considered an environmental risk and also a safety hazard. The risk of leaks of explosive gases needs to be considered against the requirements outlined in BSOR (Borehole Sites and Operations Regulations 1995) and DSEAR (Dangerous Substances and Explosive Atmospheres Regulations 2002) respectively which requires the substitution of explosive gases wherever reasonably practicable to do so. Global warming potential of compressor leaks from CNG/LNG and CO2 should also be factored into the decision. US natural gas STAR programme estimate that a newly installed reciprocating compressor may leak between 0.3 to 1.7m^3/hr and a worn compressor has seen reported leaks rates as high as 25.5m^3/hr. However, a monitoring regime and maintenance programme would control leaks rates to low levels.

The original Environmental Statement for the Preston New Road and environmental permit applications have assessed the impacts of flaring natural gas from two flares. Details of the model and associate air quality impact assessment are not appended to this BAT assessment as they have already been assessed and granted.

A supporting air quality model has been developed for the nitrogen gas lift scenario assuming pessimistic scenarios. The conclusion from the model is detailed below and the full air quality assessment which supports this document forms part of the application documents.

It should be noted that, given the nature of venting, the timing for venting cannot be scheduled at this stage. Therefore, for both long-term and short-term impacts, the model assumed that flaring and venting will be operating continuously throughout the year for 365 days, to capture the worst-case meteorological conditions that result in the maximum impact. This is considered to be a conservative approach, as in reality it is not possible for flaring and venting to occur simultaneously and venting is not anticipated to occur for more than 1 month of the year (even 1 month is understood to be a conservative scenario).

The results have also been compared against screening criteria from the Defra & EA (2016) guidance, which identified that the impacts of the development on annual mean NO2 and benzene concentrations and 1-hour mean NO2 and benzene concentrations are 'not significant'. The development was also identified as having 'not significant' impacts on local ecologically sensitive sites, with regards to nitrogen deposition, and ambient annual and daily mean NOx concentrations.

The use of nitrogen for gas lift operations at Preston New Road have therefore been shown to pose an insignificant impact on the environment.

9.0 Cost benefit assessment of available techniques

A cost benefit analysis of a nitrogen lift is compared against the indicative costs and benefits of other gases. Mechanical lifts are not considered available and therefore not factored into the assessment.

Where costs or benefits of either available option are similar for both options (for example, required storage space), these are not detailed as they will not influence to outcome of the cost benefit assessment.

Nitrogen lifting

The use of nitrogen lifting involves a number of direct and indirect costs, these include the purchase, transport and operational costs of supplying the gas, and the shadow costs of temporarily increased site emissions. However, the use of nitrogen also offers direct and indirect benefits.

Costs

Economic costs

Nitrogen gas when purchased in bulk quantities is a comparatively inexpensive gas, with costs of £0.20 per cubic meter being typical.

Further costs which are not accounted for in the analysis but would need to be considered as part of the overall cost benefit analysis will include:

- Transportation cost (£1000 - £2000 per delivery).
- N2 Compressors rental (£900 -£1200 per day)
- N2 liquefied tank rental (£100- £150 per day)

In the UK, most bulk nitrogen for use in the oil and gas sectors is sourced from outside of Lancashire. As a result, transport costs to Lancashire are comparatively high. Each load of nitrogen delivered costs approximately £1,000 – 2,000, and between 1 and 20 loads may be required to successfully lift a well.

Carbon emissions costs

Table 3 provides a comparison of venting and flaring from a gas inlet mixture which is combustible and a mixture that is incombustible. Methane being the principal component of natural gas, has a global warming potential 28 times stronger than carbon dioxide over a 100 year horizon. The direct release of methane converted to tonnes equivalent of carbon dioxide by multiplying the release mass (in tonnes) by 28, then costed using the traded and non-traded price of carbon dioxide.

Table 3: Environmental Cost of Venting & Flaring

PNR 1z Emissions estimates	Traded £35 tCo2e	Non - traded £70 tCo2e
2.7t (lower) venting*	2.7 x 28 x 35 = £2,646	2.7 x 28 x 70 = £5,292
2.7t (lower) flaring	2.7 x 35 = £94.50	2.7 x 70 = £189
6.8t (upper) venting*	6.8 x 28 x 35 = £6,664	6.8 x 28 x 70 = £13,328
6.8t (upper) flaring	6.8 x 35 = £238	6.8 x 70 = £476

*source from EA CAR Form (Reference: UP3431VF/032894)

Benefits

Due to its non-combustible properties, nitrogen is inherently safer for use in oil and gas sector applications. While less tangible, the use of nitrogen lifting also results in a number of important intangible benefits which must be taken into account in accordance with the dual objectives of the Mining Waste Directive to minimize risks to human health as well as deliver a high level of environmental protection as a whole.

Due to its non-combustible properties, nitrogen is inherently safer for use in oil and gas sector applications, see section 10.

In addition, as it is inert and already ubiquitous in atmosphere, nitrogen prevents any direct polluting effects either when in contact with deep formation groundwater, or when subsequently released to atmosphere. This absence of emission or pollutant effects represents a significant, if intangible benefit of using nitrogen for well lifting purposes.

Alternative gas lifting

The use of alternative gases involves a number of direct and indirect costs, these include the purchase, transport and operational costs of supplying the gas, the costs associated with compressing and pumping the gas using non-standard equipment, and the increased intangible costs of higher risk operations.

Costs

Cost of supply can vary due to the seasonal timing, market availability and supply chain feasibility. Engagement with the supply chain and service partners have factored in a range of costs depending on the commercial arrangements and quantities being supplied. Therefore an upper and lower cost range have been utilised to give approximate figures for each gas type.

The below table give a headline number for the cost of the gas

Gas Costs	Base Case	Other Gas Types					
	N2	**CNG**	**LNG**	**LCO2**	**Hydrogen**	**Air**	**Oxygen**
Per m3	£0.20 - £0.22	N/a	£0.38 - £0.53*	£0.47**	£4***	£0.4	£0.4
Example case Total cost 200,000m3 of gas injection	£40k – £44K	N/a	£ 76k - £106k	£94k	£800k	£90k	£90k

*Include transport costs

** Bottle bank 15 cylinder manifold

*** Hydrogen delivered per tonne due to its mass being low price is high in comparison.

CNG – costs have not been provided by supply chain partners due to lack of market application.

Consultation with supply chain partners reaffirmed that no available (rental) equipment exists for the conversion (re-gasification process) and subsequent compression of any of the proposed alternative gases for this scenario in the UK. The lack of necessary equipment within the UK and Europe significantly undermines the ‘availability’ pillar of these techniques in any BAT assessment and should therefore be disregarded as BAT.

However compressors and convertors are available to purchase. A natural gas compressor would require a capital expenditure of >£1 million subject to design specification and market availability for the compressor including the additional cost for a convertor to re-gasify liquefied gases. Due to the short duration and scope of works the capital investment is not justified for discrete exploration programme or gas lift technique which could last as little as one day. In future scenarios with a defined production programme of multiple close proximity wells, i.e. next to each other, producing consistent and pressurised natural gas, an argument to justify the capital expenditure necessary to purchase a compressor may be economically viable. This would be covered by a future production BAT assessment.

Additional intangible costs are incurred when using alternative gases (for example, due to increased pollution, safety risks etc.). While difficult to quantify, these issues add significant cost, both directly and indirectly to the use of alternative gases for well lifting purposes. Changes to well architecture and wellhead configuration fundamentally change the design of the exploration well. A particular additional cost which must also be included when considering hydrogen, oxygen or carbon dioxide is the increase maintenance and risk cost associated with accelerated wear and tear on downhole equipment and materials due to corrosivity.

Significant unknown costs resulting from elevated risks associated with downhole or below ground damage arising from explosions or downhole fires must also be considered but difficult to quantify financially.

Benefits

While less tangible, the use of alternative gases also results in some benefits. Due to their increased flammability (excluding CO_2), alternative gases are unlikely to result in natural gas being released uncombusted, thereby reducing emissions of greenhouse gases.

Cost benefit assessment conclusion

In conclusion, nitrogen gas is comparatively inexpensive, is readily available, does not result in plant damaging side effects, but may result in small quantities of natural gas being released uncombusted for a short duration. As a result, it is considered that the benefits strongly outweigh the costs of its use.

Alternative gases and associated equipment are comparatively expensive, are not readily available for this specific short term operation, can result in plant damaging effects increasing the cost of operation and importantly risk assessment shows that they would pose a significant and avoidable safety risk (See Section 10). However the flammable alternative gases may result in the avoidance of small quantities of natural gas being released uncombusted during well lifting operations. As a result, their costs and disadvantages strongly outweigh the benefits of their use.

While each available technique has both costs and benefits associated with it, the use of nitrogen lifting emerges as having the strongest relative cost benefit position of the available options.

10.0 Safety assessment of available techniques

As mentioned above, the Mining Waste Directive requires as one of its dual objectives alongside environmental protection the minimization of risks to human health. Safety risks therefore have to be taken into consideration as part of the assessment of BAT. The Hydrocarbon BREF further elaborates the point with the following:

1.3.3 BAT and risk management approaches must not compromise safety and should be consistent with related activities to ensure safety.

2.2.6 Potential Adverse Effect on Safety

It is expected that the techniques and approaches identified in the Guidance Document should be applied in such a way as to not compromise safety and should be consistent with related activities to ensure safety. The Guidance Document acknowledges that many best risk management approaches and BAT have both safety and environmental relevance and are often applied to satisfy requirements for both.

Recital (11) of the Mining Waste Directive provides:

"In order to remain true to the principles and priorities identified in Directive 75/442/EEC and, in particular, Articles 3 and 4 thereof, Member States should ensure that operators engaged in the extractive industry take all necessary measures to prevent or reduce as far as possible any negative effects, actual or potential, on the environment or on human health which are brought about as a result of the management of waste from the extractive industries."

The safety impacts of the available techniques have been considered. The requirements of general health and safety law and the particular requirements of the DSEAR and BSOR regulations place additional constraints on the techniques which Cuadrilla can use in its operations at Preston New Road.

In the particular scenario of undertaking a short term gas-based artificial lift of a well at the site, Cuadrilla must seek to implement processes and techniques which seek to balance the protection of human health (including to site staff) and the requirement to achieve a high general level of protection of the environment.

A particular constraint imposed by the DSEAR regulations is the application of the ALARP (As low as reasonably practical) principle that employer's have a duty to adhere to where the use of dangerous substances is required. In applying the ALARP principle, employers must as a first priority substitute, as far as is reasonably practicable, the presence or use of dangerous substances with an alternative which eliminates or reduces the risk. The selection of a flammable gas rather than nitrogen would be contrary to this statutory duty.

Safety assessment review

The safety assessment (Appendix A) identifies a number of major consequence, low likelihood scenarios (i.e. major accidents). Despite major accidents being rare, when weighing up the risk operators must consider a hierarchy of control to eliminate where possible and then reduce, isolate and control the risk.

In the specific scenario of a short term well completion, the use of nitrogen when compared to alternative gases, is demonstrably the safest option and aligns with the principle of ALARP.

11.0 Consideration of applicability of JRC BAT conclusions

The BAT conclusions for the management of extractive wastes, including those from oil and gas exploration activities, are contained in BAT Reference Document for the Management of Waste from Extractive Industries (European Commission, December 2018) (the 'Extractive Industries BREF').

The Extractive Industries BREF sets out a wide range of waste management issues relating to the planning, operation and decommissioning of extractive waste facilities. The Extractive Industries BREF also includes BAT conclusions, emerging techniques and commonly applied techniques in a range of extractive industries scenarios.

Of the commonly applied techniques, section 9.1 Annex 1 techniques and methods applied for the extraction of mineral resources, sub section 9.1.1 makes reference to coil tubing units which are used to perform workover jobs which includes reference to nitrogen lifts.

Sub section 9.1.1.4, well stimulation, reference to enhancing well productivity using stimulation techniques makes reference to nitrogen lifting or injection of nitrogen gas to displace well fluids in order to reduce the hydrostatic column and initiate flow from the reservoir to the surface.

The BAT conclusions from the Extractive Industries BREF which relate to the issue of nitrogen lifting are those included in Section 5.4.3, Prevention or minimisation of air pollution (BATc 51 & 52). Unlike under the Industrial Emissions Directive however, the Extractive Industries BREF is applicable only to the setting of emissions limit values rather than to the setting of other types of conditions within a mining waste permit and it is not mandatory to apply the BAT conclusions themselves.

5.4.3.3 Prevention or minimisation of emissions of VOCs and other potential air pollutants from drilling muds and other extractive wastes from oil and gas exploration and production

BAT 51. In order to prevent or minimise air pollution, BAT is to use the following techniques:

Technique		**Description**	**Applicability**	**Summary applicability**
a	*Reduced emissions completions (RECs)*	*Relevant for liquid extractive waste from well completion containing VOCs or other potential air pollutants, in particular for flowback water* <u>*Planning and design phase*</u> *To include in the design reduced emissions completions (RECs). It enables the capture of gases extracted during well completions. RECs are also called green completions or reduced flaring completions.* *The most common separation technique consists of three phase separators used to separate first the sand from the outflow and then the gas from the water and condensate.*	*Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5).* *Small volumes of collectable gases may limit the applicability of the technique in the exploration phase.*	Applicable to exploration phase. Intention and design of nitrogen lift is short term and temporary. Separator designed into site well test package. Small volumes of collectable gases due to nitrogen limits the ability of

		The separated gas is sent to a dehydrator to remove the residual water prior to distribution. *<u>Operational (construction, management and maintenance) phase</u>* *To implement REC, while applying management systems (see BAT 1 and BAT 12).*		enclosed flares to combust methane gas.

5.4.3.4 Monitoring of emissions to air

BAT 52. BAT is to monitor emissions to air as follows:

Technique	**Description**	**Applicability**	**Summary applicability**
Monitoring of emissions to air	*Planning and design phase* *To develop a monitoring plan for emissions to air through the following activities:* *Identification of the possible emission sources considering both point and diffuse sources. This may include modelling of diffuse emissions, which encompasses fugitive emissions (e.g. EN 15445:2008).* *Planning the monitoring of emissions to air and the efficiency of the measures applied for prevention and reduction of these emissions. This may include monitoring of ambient air quality and dust deposition from diffuse emissions while using meteorological data.* *Monitoring parameters and frequencies are properly selected according to the site-specific conditions, including the extractive waste characteristics, with particular regard to the potential risk of air pollution, as identified in the Environmental Risk and Impact Evaluation and reflected in the EWMP, taking into account existing monitoring activities and in line with applicable legal provisions.*	*Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5).*	Cuadrilla has in place a monitoring plan approved by the Environment Agency (EMMP version 5.1) as part of pre-operational condition PO2.

	To this end, the parameters and frequencies in Table 4.57 may be considered. *If the emissions to air from the extractive waste management are considered together with those from other activities, an integrated monitoring plan may be developed.* *Monitoring is planned in accordance with EN standards. If EN standards are not available, BAT is to use ISO, national or other international standards that are developed according to equivalent principles of consensus, openness, transparency, national commitment and technical coherence as for EN standards.*		

12.0 BREF Compliance

When all factors are considered, including effectiveness, viability, operational, safety, environmental and economic, nitrogen lifting emerges as the most advantageous technique for artificially lifting a well, while still achieving a high general level of protection of the environment and the prevention or reduction of safety risk. As a result, Cuadrilla considers the technique of nitrogen lifting aligns with BAT conclusions 51 and 52.

A BAT determination requires that an operator meets at least the best environmental outcomes that other operators are able to achieve using available techniques for the same activity. Nitrogen lifting is a common technique used by multiple alternative UK operators to achieve an artificial lift of a hydrocarbon well as part of a well completion or following other well interventions. Nitrogen lifting has been utilised on multiple occasions in recent years for the same purpose as Cuadrilla are seeking to undertake. As such, we consider that short term nitrogen lifting at Preston New Road will achieve a comparable level of environmental outcome as other operators.

13.0 Waste management plan implications

As outlined in the sections above, a number of possible techniques have been considered to artificially lift a well at the start of well testing operations. It has been determined that the use of nitrogen lifting is the best available technique based.

The process of lifting a well is inherently uncertain, particularly for a newly drilled and hydraulically fractured well as it is not certain whether a well will flow, how much it will flow and in some cases what it will flow (crude oil, natural gas, condensate or a mixture). As a result, during the initial period of lifting a well, the fluid which returns will, for a period of time, be of uncertain composition.

During exploratory activities, the exact nature of the returning fluid takes on a greater importance, as it is likely to be a waste which must be characterized, estimated and managed in line with a site's permitted operating techniques.

At the Preston New Road site, two enclosed high temperature flares have been permitted as BAT for the disposal of waste gases arising from the well during exploratory activities. The flares installed are high capacity flares designed for relatively rich (that is, highly combustible) waste gases within a relatively narrow operational envelope.

During the well completion of the PNR 1z well at the Preston New Road, it became apparent that significant lifting of the well was required to initiate a flow of hydrocarbons. As a result, for a limited period (e.g. days to weeks), the returning fluids from the well were a gaseous mixture dominated by nitrogen with lower and variable quantities of natural gas. Despite every reasonable effort, it was not possible ignite and combust this gas, even in the presence of permanently lit pilot lights and the use of injected support fuel.

During the lifting of the well at the Preston New Road site, it has transpired that under certain circumstances, the waste stream while still nominally flammable (>4.4%v/v methane) is in fact not combustible. As a result, small quantities of natural gas have been emitted uncombusted despite having passed through a lit pilot flame within the flares. Whilst there is a reasonable expectation that at concentration of ≥30% v/v methane combustion will occur, there is some risk that at concentrations up to 50% v/v methane, incombustible mixtures may be generated due to the inherent variability of gas composition flowing from the well. However the higher the concentration of methane the lower the likelihood of non-combustion.

To minimise fugitive emissions, it has been found not to be appropriate to commence support fuel injection after five minutes of such flow conditions (<20%v/v methane). This is due to the returning gas phase remaining incombustible even after the addition of support fuel. In these circumstances, adding support fuel simply increases, rather than decreases, the level of VOC emissions from the process (contrary to relevant BAT conclusions), and incurs additional cost for no environmental benefit.

To minimise overall VOC emissions during nitrogen lifting, Cuadrilla will undertake all reasonable measures to ensure the returning well fluids are combusted as soon as it is possible to do so. To do this, systematic checks will be undertaken at various methane concentrations below and above the empirically observed incombustible level of 30%, (e.g. 20%, 25% and 30% etc). A cost benefit analysis has been conducted to assess the environmental and economic costs and benefits of introducing propane. The CBA outlines how the propane enhances the calorific value of the gas stream within the design parameters of the flare system. The CBA accounts for the environmental costs associated with venting methane balanced against the environmental costs and economic implications of introducing propane. It concludes that adding support fuel at methane concentration levels of ≥20% v/v could provide a modelled overall benefit, and hence this concentration level has been selected for the first systematic check. Each concentration check will involve the temporary addition of support fuel to test whether a combustible mixture can be achieved. Where combustion cannot be initiated or sustained, support fuel use will be withdrawn until the next methane 'set point' is reached at which stage, the addition of support fuel will be tested again. Once an effective methane concentration set point has been established (that is, the point at which combustion becomes possible), this will become the point at which the process outline in Table 5.1 of PO10 Flare Operational & Control Plan will be instituted.

Once combustible returns from the well have been achieved, the flares will then be operated in accordance with the existing permit conditions unless and until natural gas concentrations returning from the well once again fall below the combustion threshold. If this scenario is realised, support fuel will be temporarily withdrawn to minimise any VOC emissions arising.

During periods of incombustible well returns, continuous methane monitoring will remain in place throughout in line with the requirements of the site's Environmental Management and Monitoring Plan (EMMP). Any detected elevations of background methane or TVOC levels will be notified to the Environment Agency within 24 hours.

14.0 BAT Assessment Outcome

A range of techniques have been considered for artificially lifting exploration wells at Preston New Road site. It has been determined that nitrogen lifting represents the best available technique based on safety, economic and environmental assessments. There are clear and unavoidable risks and design flaws associated with each alternative gases and mechanical techniques.

When assessed in balance, it is judged that the use of nitrogen alongside the use of enclosed flares for the management of waste natural gas during a short term well completion is the only available option for the particular circumstances of the Preston New Road operations. As a result, Cuadrilla considers that nitrogen lifting represents the best available technique for artificial well lifting at the exploration Preston New Road site.

15.0 References

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16.0 Appendix A Safety Risk Assessment

Objective

This assessments considers the comparative risk to human health of using a gas as an artificial lift during an exploration well completion.

Scope

The scope of the assessment covers exploration projects only after a well has been hydraulically fractured. This report does not consider environmental impacts.

References

CORP-HSE-PRD—002 Identification of HSE Risks Procedure

Regulation

The safety impacts of the available techniques have been considered. The requirements of general health and safety law and the particular requirements of the Management of Health and Safety at Work Regulations 1999, the Dangerous Substances and Explosive Atmospheres Regulations 2002 (DSEAR) and Borehole Sites and Operations Regulations 1995 (BSOR) place additional constraints on the techniques which Cuadrilla can use in its operations at Preston New Road.

During the short term gas-based artificial lift of a well at the site, Cuadrilla must ensure, so far as is reasonably practicable, the health, safety and welfare at work of all employees.

A particular constraint imposed by the DSEAR regulations is the application of the ALARP (As low as reasonably practical) principle that employers have a duty to adhere to where the use of dangerous substances is required. In applying the ALARP principle, employers have a particular duty to preferentially substitute, as far as is reasonably practicable, the presence or use of dangerous substances with an alternative which eliminates or reduces the risk.

Appendix A1 Liquid Nitrogen used for Gas Lift

Operational phase	Scenario	Existing Controls	Likelihood	Likelihood	Consequence	Consequence (severity)	Residual Risk based on existing controls	Risk
Transportation (note that the supplier is responsible for the safe delivery of the Liquefied nitrogen LN2)	Small weep from transportation container	Haulier and LN2 supplier selected based on tender evaluation process which includes HSE.	Low likelihood due to low pressure and minimal number of flanged joints and valves.	1	Local weep of N2, rapidly dispersed.	1	Low	1
	Catastrophic release from transportation container due to HGV accident.	As above.	HGV speed limited. Very low likelihood of catastrophic failure due to an accident.	1	LN2 (very cold) spilled onto road. Potential damage to road. Likely to disperse rapidly.	3	Low	3
Storage at site, evaporation/pumping of LN2, and injection downhole. LN2 is stored in ISO container at site.	Small weep from storage equipment	LN2 will be stored in the bulk carrier used for transportation. LN2 storage and processing areas will have restricted access. Operators will be trained and competent in LN2 handling/processing. Equipment monitoring will be in place during use.	Low likelihood due to low pressure and minimal number of flanged joints and valves.	2	Local weep of N2, rapidly dispersed. Unlikely to have an impact due to extreme cold temperature.	1	Low	2
	LN2 is stored in ISO container at site. Catastrophic release due to impact from vehicle or dropped object.	As above. Lifting over LN2 storage and lines will be strictly controlled.	Very low likelihood. No lifting over LN2	1	Liquid N2 (very cold) spilled onto well pad. Potential damage to area (well pad matting). Likely to disperse rapidly.	3	Low	3
Flowback and gas stream disposal.	Small weep from above ground facilities.	Equipment is leak tested as part of facilities	Low likelihood due to low pressure and minimal number of	2	Local weep of N2, rapidly dispersed.	1	Low	2

N2 is flowed back to surface and flows through separator then to flare (with pilots burners lit).		commissioning. Routine leak detection programme is in place.	flanged joints and valves.					
	Catastrophic release due to total integrity loss (for example due to dropped object onto pipework)	As above. Lifting over process lines is strictly controlled.	Extremely low likelihood as no lifting over separator pipework/facilities.	1	Local release of gaseous N2.	1	Low	1

Appendix A2 LNG/CNG used for Gas Lift

Operational phase	Scenario	Existing Controls	Likelihood	Likelihood	Consequence	Consequence (severity)	Residual Risk based on existing controls	Risk
Transportation	Small weep from transportation container	Haulier and LNG/CNG supplier selected based on tender evaluation process which includes HSE.	Low likelihood due to low pressure and minimal number of flanged joints and valves.	1	Local weep of natural gas, rapidly dispersed. Potential for explosive atmosphere.	3	Low	6
	Catastrophic release from transportation container due to HGV accident.	As above.	HGV speed limited. Low likelihood of catastrophic failure due to an accident.	1	LNG (very cold) or pressurised CNG spilled onto road. Potential damage to road. Likely to disperse rapidly. Potential to ignite leading to explosion/ fire	5	Medium	5
Storage at site, evaporation/pumping of LNG/CNG and injection downhole. LNG is stored in ISO container at site.	Small weep from storage equipment	LNG will be stored in the bulk carrier used for transportation. LNG storage and processing areas will have restricted access. Operators will be trained and competent in LNG/CNG handling/processing. Equipment monitoring will be in place during use.	Low likelihood due to low pressure and minimal number of flanged joints and valves.	1	Local weep of LNG, CNG rapidly dispersed. LNG unlikely to have an impact due to extreme cold temperature. Pressurised gas potential to ignite and escalate to major event. Release of Mercaptan into atmosphere	3	Low	3

Operational phase	Scenario	Existing Controls	Likelihood	Likelihood	Consequence	Consequence (severity)	Residual Risk based on existing controls	Risk
		Mercaptan used to identify gas.			creating odour issues.			
	Catastrophic release due to impact from vehicle or dropped object.	As above. Lifting over LNG storage and lines will be strictly controlled.	Low likelihood. No lifting over LNG/CNG	1	LNG (very cold) spilled onto well pad. Potential damage to area (well pad matting). Potential to ignite given large number of vehicles on well pad. Likely to disperse rapidly. CNG leaks creating explosive/ flammable gas cloud	5	Medium	5
Injecting natural gas	Injecting pressurised natural gas into wellhead down wellbore CT annulus	Exploration wellhead requires re-configuration (check valves, emergency shut down, back pressure valves). Not standard practice for a short term gas lift based on the risk consequence.	Low likelihood of explosive risk due to lack of ignition source	1	Explosive/ flammable gas injected down annulus.	5	Medium	5
Flowback and gas stream disposal. Natural gas is flowed back to surface and flows	Small weep from above ground facilities.	Equipment is leak tested as part of facilities commissioning. Routine leak	Low likelihood due to low pressure and minimal number of	2	Local weep of natural gas, rapidly dispersed. Unlikely to ignite.	1	Low	2

through separator then to flare (with pilots burners lit).		detection programme is in place.	flanged joints and valves.					
	Catastrophic release due to total integrity loss (for example due to dropped object onto pipework)	As above. Lifting over process lines is strictly controlled.	Extremely low likelihood as no lifting over separator pipework/facilities.	1	Local release of gaseous natural gas. Potential flammable gas leasing to fire/explosion.	5	Medium	5

Appendix A3 CO2 used for Gas Lift

Operational phase	Scenario	Existing Controls	Likelihood	Likelihood	Consequence	Consequence (severity)	Residual Risk based on existing controls	Risk
Transportation	Small weep from transportation container	Haulier and CO2 supplier selected based on tender evaluation process which includes HSE.	Low likelihood due to low pressure and minimal number of flanged joints and valves.	1	Local weep of natural gas, rapidly dispersed.	1	Low	1
	Catastrophic release from transportation container due to HGV accident.	As above.	HGV speed limited. Very low likelihood of catastrophic failure due to an accident.	1	Liquid CO2 (very cold) spilled onto road. Potential damage to road. Likely to disperse rapidly.	4	Medium	4
Storage at site, evaporation/pumping of CO2, and injection downhole. CO2 is stored in ISO container at site.	Small weep from storage equipment	CO2 will be stored in the bulk carrier used for transportation. CO2 storage and processing areas will have restricted access. Operators will be trained and competent in CO2 handling/processing. Equipment monitoring will be in place during use.	Low likelihood due to low pressure and minimal number of flanged joints and valves.	2	Local weep of CO2, rapidly dispersed. Unlikely to have an impact due to extreme cold temperature.	1	Low	2
	CO2 is stored in ISO container at site. Catastrophic release due to impact from vehicle or dropped object.	As above. Lifting over CO2 storage and lines will be strictly controlled.	Low likelihood. No lifting over CO2	1	Liquid CO2 (very cold) spilled onto well pad. Potential damage to area (well pad matting). Likely to disperse rapidly.	2	Low	2

Downhole Well integrity	Acidification of water	Monitoring of annulus pressure	Carbonic acid due to mixing of formation water/ water with CO2	4	Corrosion of wellbore integrity	3	High	8
	Pressure drop	Maintain wellbore pressure and surface lines	Pressure drop leading to carbon ice blockage	4	Blockage in lines preventing or restricting gas flow to surface. Pressure build up in lines.	3	High	12
Flowback and gas stream disposal. CO2 is flowed back to surface and flows through separator then to flare (with pilots burners lit).	Small weep from above ground facilities.	Equipment is leak tested as part of facilities commissioning. Routine leak detection programme is in place.	Low likelihood due to low pressure and minimal number of flanged joints and valves.	2	Local weep of CO2, rapidly dispersed.	1	Low	2
	Catastrophic release due to total integrity loss (for example due to dropped object onto pipework)	As above. Lifting over process lines is strictly controlled.	Low likelihood as no lifting over separator pipework/facilities.	1	Local release of gaseous CO2.	3	Low	3

Appendix A4 Air used for Gas Lift

Operational phase	Scenario	Existing Controls	Likelihood	Likelihood	Consequence	Consequence (severity)	Residual Risk based on existing controls	Risk
Transportation	Small weep from transportation container	Haulier and air supplier selected based on tender evaluation process which includes HSE.	Low likelihood due to low pressure and minimal number of flanged joints and valves.	2	Local weep of air, rapidly dispersed.	1	Low	2
	Catastrophic release from transportation container due to HGV accident.	As above.	HGV speed limited. Low likelihood of catastrophic failure due to an accident.	1	Pressurised air causing release of energy causing potential damage or projectiles into site. Air will disperse rapidly.	4	Medium	4
Storage at site, evaporation/pumping of pressurised air, and injection downhole. Air is stored in ISO container at site.	Small weep from storage equipment	Air will be stored in the bulk carrier used for transportation. Air storage and processing areas will have restricted access. Operators will be trained and competent in air handling/processing. Equipment monitoring will be in place during use.	Low likelihood due to high pressure and minimal number of flanged joints and valves.	2	Local weep of air, rapidly dispersed. Will not have an impact.	1	Low	2
Injection of air into wellbore liquid.	Oxidation of downhole equipment	Use of oxygen scavengers Annulus monitoring	High likelihood of oxidation with high quantity of oxygen pumped into wellbore	4	Well integrity compromised	3	High	12
Flowback and gas stream disposal. Air is flowed back to surface and flows through	Small weep from above ground facilities.	Equipment is leak tested as part of facilities commissioning. Routine leak	Low likelihood due to low pressure and minimal number of flanged joints and valves.	2	Local weep of air, rapidly dispersed.	1	Low	2

separator then to flare (with pilots burners lit).		detection programme is in place.						
	Catastrophic release due to total integrity loss (for example due to dropped object onto pipework)	As above. Lifting over process lines is strictly controlled.	Low likelihood as no lifting over separator pipework/facilities.	1	Local release of gaseous air under pressure.	3	Low	3

Appendix A5 Hydrogen used for Gas Lift

Operational phase	Scenario	Existing Controls	Likelihood	Likelihood	Consequence	Consequence (severity)	Residual Risk based on existing controls	Risk
Transportation	Small weep from transportation container	Haulier and hydrogen supplier selected based on tender evaluation process which includes HSE.	Low likelihood due to low pressure and minimal number of flanged joints and valves.	2	Local weep of hydrogen, rapidly dispersed.	1	Low	2
	Catastrophic release from transportation container due to HGV rollover.	As above.	HGV speed limited. Very low likelihood of catastrophic failure due to an accident.	1	Liquid hydrogen (very cold) spilled onto road. Potential damage to road. Likely to disperse rapidly.	4	Medium	4
Storage at site, evaporation/pumping of pressurised hydrogen, and injection downhole.	Small weep from storage equipment	Hydrogen will be stored in the bulk carrier used for transportation. Hydrogen storage and processing areas will have restricted access. Operators will be trained and competent in Hydrogen handling/processing. Equipment monitoring will be in place during use.	Medium likelihood due to high pressure and minimal number of flanged joints and valves.	2	Local weep of hydrogen, rapidly dispersed. Will not have an impact.	1	Low	2
Surface equipment and injection downhole	Corrosion due hydrogen embrittlement	Not compatible with site surface and subsurface equipment	Likelihood of embrittlement Failure may occur with little or no warning as cracks start internally	3	Well integrity compromised Surface equipment integrity compromised.	3	Medium	9

Flowback and gas stream disposal. Hydrogen is flowed back to surface and flows through separator then to flare (with pilots burners lit).	Small weep from above ground facilities.	Equipment is leak tested as part of facilities commissioning. Routine leak detection programme is in place.	Low likelihood due to low pressure and minimal number of flanged joints and valves.	2	Local weep of hydrogen, rapidly dispersed.	1	Low	2
	Catastrophic release due to total integrity loss (for example due to dropped object onto pipework)	As above. Lifting over process lines is strictly controlled.	Extremely low likelihood as no lifting over separator pipework/facilities.	1	Local release of gaseous explosive hydrogen under pressure.	5	Medium	5

Appendix A6 Oxygen used for Gas Lift

Operational phase	Scenario	Existing Controls	Likelihood	Likelihood	Consequence	Consequence (severity)	Residual Risk based on existing controls	Risk
Transportation	Small weep from transportation container	Haulier and oxygen supplier selected based on tender evaluation process which includes HSE.	Low likelihood due to low pressure and minimal number of flanged joints and valves.	2	Local weep of oxygen, rapidly dispersed.	2	Low	2
	Catastrophic release from transportation container due to HGV accident.	As above.	HGV speed limited. Low likelihood of catastrophic failure due to an accident.	1	Pressurised oxygen released onto road, potential damage. Likely to disperse rapidly. Explosive environment from pressurised release of oxygen.	5	Medium	4
Storage at site, evaporation/pumping of pressurised hydrogen, and injection downhole.	Small weep from storage equipment	Oxygen will be stored in the bulk carrier used for transportation. Oxygen storage and processing areas will have restricted access. Operators will be trained and competent in Oxygen handling/processing. Equipment monitoring will be in place during use.	Low likelihood due to high pressure and minimal number of flanged joints and valves.	2	Local weep of oxygen, rapidly dispersed. Will not have an impact.	3	Medium	6
Injection of air into wellbore liquid.	Oxidation of downhole equipment	Use of oxygen scavengers Annulus monitoring	Medium likelihood of oxidation with high quantity of oxygen pumped into wellbore	4	Well integrity compromised	3	High	12

Flowback and gas stream disposal. Hydrogen is flowed back to surface and flows through separator then to flare (with pilots burners lit).	Small weep from above ground facilities.	Equipment is leak tested as part of facilities commissioning. Routine leak detection programme is in place.	Low likelihood due to low pressure and minimal number of flanged joints and valves.	2	Local weep of oxygen, rapidly dispersed.	1	Low	2
	Catastrophic release due to total integrity loss (for example due to dropped object onto pipework)	As above. Lifting over process lines is strictly controlled.	Low likelihood as no lifting over separator pipework/facilities.	1	Local release of gaseous oxygen under pressure creating explosion.	5	Medium	5

Qualitative Risk Assessment Scoring Matrix

Severity \ Likelihood	1	2	3	4	5
1	**1**	**2**	**3**	**4**	**5**
2	**2**	**4**	**6**	**8**	**10**
3	**3**	**6**	**9**	**12**	**15**
4	**4**	**8**	**12**	**16**	**20**
5	**5**	**10**	**15**	**20**	**25**

Severity of harm most likely to arise from the hazard:

1 = Minor Discomfort, First Aid Cases, Low-level impacts on biological or physical environment.

2 = Reversible injuries, Medical Treatment (MTC), Minor effects on biological or physical environment.

3 = Reversible injuries, Restricted Work Day Cases (RWDC), Lost Time Incidents (LTI) Moderate effects on biological or physical environment.

4 = Single fatality, Permanent disability, irreversible illness, Serious environmental effects.

5 = Multiple fatalities, multiple irreversible illnesses, Very serious environmental effects.

Likelihood of the potential incident:

1 = Rare

2 = Unlikely

3 = Moderate

4 = Likely

5 = Very Likely

Risk Rating = Severity x Likelihood

The priority of actions arising from the assessment depends on the overall risk rating.

Risk rating of:

15 – 25 = Very High Priority

10 – 12 = High priority

4 – 9 = Medium priority

1 – 3 = Low priority

Risk Factor	Action Required
Low	Continuous risk management must be embedded within Cuadrilla Resources Ltd's occupational health and safety activity with the aim of reducing the risk.
Medium	Short-term risk mitigation shall be implemented while the appropriate Manager approval is obtained to manage the risk as part of an overall program of continuous risk reduction.
High	For continued operation, the appropriate Manager shall be promptly notified. A short-term risk mitigation plan shall be implemented promptly while the appropriate Manager approval is obtained for a longer term risk mitigation plan.
Very High	For continued operation, the Executive team shall be promptly notified. A short-term risk mitigation plan shall be implemented promptly while the approval from the Executive team is obtained for a longer term risk mitigation plan.