H2Teesside Project

Environmental Permit Application Reference: [EPR/AP3328SQ/A001]

Land at and in the vicinity of the former Redcar Steel Works site, Redcar and in Stockton-on-Tees, Teesside

Appendix C1 Assessment of Best Available Techniques for Emerging Techniques for Hydrogen Production with Carbon Capture

Environmental Permitting (England and Wales) Regulations 2016

Applicants: H2 Teesside Ltd

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GLOSSARY

Abbreviation	Description
Applicant/Operator	H2 Teesside Ltd
ATR	Auto Thermal Reforming
BAT	Best Available Techniques
BAT-AEL	BAT- Associated Emission Level
CCP	Carbon Capture Plant
CCS	Carbon Capture and Storage
CCUS	Carbon Capture, Usage and Storage
CO_2	Carbon dioxide
DCS	Distributed Control System
ELV	Emission Limit Value
EMS	Environmental Management System
ETHPCC	Emerging Techniques for Hydrogen Production With Carbon Capture
ETP	Effluent Treatment Plant
FEED	Front-End Engineering Design
FID	Final Investment Decision
GHR	Gas Heated Reformer
H_2	Hydrogen (gaseous)
IP	Intermediate Pressure
ITS	Iso Thermal Shift
LCP	Large Combustion Plant
LHV	Lower Heating Value
LTS	Low Temperature Shift
MP	Medium Pressure
NEP	Northern Endurance Partnership
NWL	Northumbrian Water Limited

Abbreviation	Description
NZT	Net Zero Teesside
O_2	Oxygen
PSA	Pressure Swing Adsorption
WwTW	Wastewater Treatment Works

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TABLES

1 OVERVIEW

1.1.1 This report has been prepared by AECOM Limited ('AECOM') on behalf of H2 Teesside Ltd ('H2TS') referred to as "the Operator", in support of the application for an environmental permit for the proposed Carbon Capture (CC) enabled Hydrogen (H_2) Production Facility in the Teesside industrial cluster area in Redcar, Stockton-on-Tees.

1.1.2 The purpose of this report is to demonstrate that the proposed Installation will be designed and operated in accordance with indicative best available techniques (BAT) for emerging techniques for hydrogen production with carbon capture ('blue hydrogen' production).

1.1.3 The Hydrogen Production Facility (hereafter referred to as the 'Installation') is subject to ongoing technical studies; however, it is expected to comprise a 1.2-Gigawatt Thermal (GWth) (Phase 1, 600-Megawatt thermal (MWth) LHV and Phase 2, 600 MWth LHV) Lower Heating Value (LHV) Carbon Capture (CC) enabled Installation. It will be supported by a natural gas supply connection for the supply of natural gas to the Installation, utility connections (including water and electricity) along with pipelines to export the H_2 gas and carbon dioxide (CO_2). The CO_2 captured from the Installation will be transported (via the export/transport pipeline) for secure storage within the Endurance saline aquifer, located 145 kilometres offshore from Teesside, under the North Sea. The Installation is estimated to have a capacity to export approximately 1.27 megatonnes (Mt) of dehydrated and compressed CO_2 per year per phase, i.e. approximately 2.54 Mt/year once both phases are operational (100% utilisation) to NEP for offshore underground storage. No temporary CO_2 storage is required on site.

1.1.4 A high-level process flow diagram (Figure 3) and process flow diagrams (PFD) for the Installation are provided in Appendix A (Drawings and Plans) to the main supporting statement (Document Reference: AP3328SQ-APP-SS).

1.1.5 The proposed Installation will be designed to optimise the capture of carbon from the hydrogen production plant, while minimising emissions and waste generation and maximise energy efficiency. While individual BAT assessments have been prepared to demonstrate application of best available techniques for Blue Hydrogen Production, Large Combustion Plant, Energy Efficiency, and Cooling, the system will be integrated to address multimedia effects across the Installation as a whole.

1.1.6 The electrical, steam, steam condensate and water circuits between the hydrogen production and capture plant will be integrated as far as reasonably practicable in order to reduce energy use, as discussed in the Energy Efficiency BAT Assessment in (Appendix C4; Document Reference: AP3328SQ-APP-BAT4-EE).

1.1.7 This BAT assessment has been prepared using concept engineering information provided by the Operator related to initial design parameters of the proposed Installation, available information about the local environment and the existing standards and guidelines presented in published guidance for Emerging Techniques for Hydrogen Production With Carbon Capture(1).

1.1.8 The main application document (Document Reference: AP3328SQ-APP-SS "Supporting Statement") provides an overall view of the permit application.

1.1.9 This document should be read with the Supporting Statement (Document Reference: AP3328SQ-APP-SS) which provides a detailed description of the operations to be undertaken at the proposed Installation and how it will be operated in Section 4.

1.1.10 For assessment of BAT for large combustion plant, cooling, energy efficiency and emissions management please refer to the separate assessments:

- BAT Assessment for Large Combustion Plant (Appendix C2; Document Reference: AP3328SQ-APP-BAT2-LCP).
- BAT Assessment for Cooling (Appendix C3; Document Reference: AP3328SQ-APP-BAT3-COOL).
- BAT Assessment for Energy Efficiency (Appendix C4; Document Reference: AP3328SQ-APP-BAT4-EE).
- BAT Assessment for Emissions Management (Appendix C5; Document Reference: AP3328SQ-APP-BAT5-Emissions).

2 APPROACH TO BAT APPRAISAL

2.1.1 Article 3 (10) of the Industrial Emissions Directive (IED)(2) defines BAT as "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 designed to prevent and, where not practicable, generally reduce emission and impact on the environment as a whole".

2.1.2 The development of the hydrogen production plant from concept to full commercial scale must proceed alongside the emerging BAT regulatory positions, so there is confidence that the project meets indicative BAT before it proceeds with Front-End Engineering Design (FEED) and to drive the vendor procurement processes, whilst maintaining the best protection for the environment as a whole.

2.1.3 At this stage of project development, while the technology provider for the hydrogen production with carbon capture processes has been selected, the Installation has yet to undergo FEED and we have therefore applied an approach to the derivation of BAT which is driven by:

- The technology licensors requiring commercial confidentiality of aspects of their technology process details to be maintained;
- To allow the FEED process to progress without limiting options for later technology selections;
- To determine indicative BAT and BAT Achievable Emission Levels (BAT-AELs) for the plant which are consentable, taking into consideration the environmental sensitivities and conditions at the site.

2.1.4 The techniques described in this report and the associated BAT assessments are therefore based on the currently anticipated approaches to optimising both hydrogen production and carbon capture efficiencies.

2.1.5 The approach to BAT has been agreed with the Environment Agency (EA) during the pre-application discussions.

3 TECHNIQUE SELECTION

Introduction

3.1.1 The Emerging Techniques for Hydrogen Production With Carbon Capture(1) sets out the requirements for evaluating the selection of the techniques for choosing a H_2 and CC plant configuration based on its overall environmental performance, including:

- Energy efficiency
- Resource efficiency
- CO_2 capture efficiency
- Emissions to the environment.

3.1.2 This assessment considers the H_2 production methods available with regards to their overall environmental performance and provides a justification for the technique chosen.

Broad Assessment of Technology Options for Hydrogen Production

3.1.3 The current Emerging Techniques guidance confirms that the H_2 production methods considered by the regulator are:

- Steam methane reforming (SMR)
- Autothermal reforming (ATR)
- Gas heated reforming (GHR)
- Partial oxidation (POX)
- Combinations of these such as GHR with ATR or GHR with SMR.

3.1.4 The wide range of options was considered during the initial stages of project development and is summarised in Table 1 on the following page. From Table 1 it can be seen that the ATR based option presented the best overall energy conversion. The proposed Installation is designed to deliver a carbon capture rate of 95% in accordance with current BAT guidance and has the potential capacity to further increase the capture rate to meet potential future regulatory changes.

3.1.5 The Operator took forward two potential syngas generation technology options for consideration. These are referred to as:

- Case A, ATR based reforming; and
- Case B, a proprietary low carbon syngas technology which combines the use of a GHR with an ATR

Table 1. Broad Technology Selection

	Unit	GHR+ATR+PSA	POX + Methanation	SMR +PCC +PSA
Power / Energy Efficiency				
Gross Feed Gas Energy Conversion	% energy content of H_2 product /energy content feed gas (LHV basis)	80.6	76.6 + 3.1 (a)	67
Net feed gas energy conversion (b)	% energy content of net H_2 product /energy content feed gas (LHV basis)	70.5	70.5 +3.1 (a)	67
Electrical Power Consumption (c)	MJ / kg H_2 (after electrical power generation)	8.8	5.6	0
Overall Energy Conversion	% Energy content of H_2 product (LHV) / overall energy input (LHV including power import)	76.1	73.2 + 3.0	67
Resources				
Feedstock	Type	Natural Gas	Natural Gas	Natural Gas
Process Water Consumption (d)	Kg H_2O / kg gross H_2	3.8	2.4	5.3
Emissions				
CO_2 emissions to air from installation	Kg CO_2 / Gross H_2 (Kg CO_2 / Net H_2)	0.3 – 0.4 (0.34 – 0.46) (e)	0.0 (0.36) (f)	1.0 (g) (0.5) (h)
Carbon Capture Performance				
CO_2 Capture – Pre-combustion	Kg CO_2 /kg Gross H_2	8.4	8.4	0
CO_2 Capture – Post Combustion	Kg CO_2 /kg Gross H_2	0	0	9.2 / 9.7(i)
Overall CO_2 Capture	Kg CO_2 /kg Gross H_2	8.4	8.4	9.2 / 9.7(i)
CO_2 Capture – Pre-combustion	Kg CO_2 /kg Net H_2	9.6	9.1	0
CO_2 Capture – Post Combustion	Kg CO_2 /kg Net H_2	0	0	9.2 / 9.7(i)
Overall CO_2 Capture	Kg CO_2 /kg Net H_2	9.6	9.1	9.2 / 9.7(i)
Total CO2 Capture Efficiency	% kg C captured /kg C in feed gas	95 97	96 -97 (j)	90/95

Source: Environment Agency, January 2023, "Review of Emerging Techniques for Hydrogen Production From Methane and Refinery Gas With Carbon Capture",

Notes

a) For PO_X with methanation, 3.1% of feed gas energy retained in hydrogen product in the form of methane – i.e. converted from carbon monoxide/CO_2 as part of the purification step. This avoids use of pressure swing adsorption, with the loss of H_2 product in the associated tail gas stream, for which there is no requirement for use as fuel in the process.

b) The Net H_2 Product is equal to the Gross H_2 Product minus the amount of H_2 that would be required to generate the imported electricity. This is assumed in the values shown here to be generated using a Combined Cycle Gas Turbine fuelled by H_2 with a 58.5% LHV overall efficiency (based on the top of range of the BAT-associated energy efficiency level for combined cycle gas turbines in the range 50-600 MWth from Table 23 of the Large Combustion Plant BAT conclusions, 2017. BAT Conclusions for large combustion plant

c) The electrical power consumption in each case is on a broadly comparable basis, although with some differences in assumptions, for example around CO_2 delivery pressure.

d) Water consumption is made up of water used in reaction to produce H_2 and CO_2 plus any condensed water from the process that is not re-used and blowdown from the steam and cooling systems. The data provided by technology is unlikely to be on a fully comparable basis.

e) Based on ~100% CO_2 capture upstream of the PSA unit, with combustion of the remaining carbon monoxide and methane in the tail gas from the PSA unit to fire auxiliary heater and boiler without further abatement.

f) Based on ~100% CO_2 capture including methanation unit producing 98 mol% hydrogen product. The hydrogen product when combusted offsite will produce approximately 0.33 kg CO_2 per kg H2 product.
g) Based on 90% CO_2 post-combustion capture from reformer furnace flue gas.
h) Based on the expected 95% CO_2 post-combustion capture from reformer furnace flue gas.
i) Lower value based on 90% CO_2 capture and higher value based on 95% CO_2 capture.
j) Based on ~100% CO2 capture upstream of a methanation plant producing 68% H2 product. The H2 product will contain 3 – 4% of the carbon from the feed. There are no direct CO emissions from the H2 production or methanation units.

Technology Choice for Hydrogen Production

3.1.6 The two potential technology options was considered further and a summary of the key differences between Case A and Case B is provided in Table 2.

Table 2. Comparison of Technology Case A and Case B

	CASE A(1)	CASE B(1)
Technology	Autothermal Reforming (ATR)	Proprietary Gas Heated Reformer (GHR) – ATR combination process
Process Heat Integration	Process heat is used to generate power (via steam turbine)	Process heat is used to drive reforming reaction in a GHR
H_2 Purity	>98 mol%	> 99 mol%
CO_2 Capture Rate	95%	>95%
Process Condensate	Stripped with steam to reduce the methanol/ NH_3 content prior to water treatment	No stripper column and thus has a higher methanol/ NH_3 compositional potential in the process condensate. An additional biological treatment step is required as part of the water treatment configuration.
Liquid Effluent Flow	Higher	Lower
Cooling Water Flow	Higher	Lower
Gaseous Effluent Flow	Lower	Higher
Natural Gas Consumption	Higher	Lower
Power Import	Lower	Higher
Overall Energy Efficiency	Lower	Higher
1. Refer to the Section 2.1 of Confidential Technical Sheet for data.		

3.1.7 Based on the above assessment, Case B, the proprietary Johnson Matthey (JM) LCH technology with amine based carbon capture technology was selected. The LCH technology involves a Gas-heated reformer (GHR) coupled with an Autothermal Reformer (ATR). This H_2 production and CC plant configuration has been selected based on maximising energy efficiency, resource efficiency, and CO_2 capture efficiency, and minimising emissions to the environment.

3.1.8 The Installation produces H_2 product for transport for off-site use and uses a portion of H_2-rich tail gas produced in the process to raise steam within the auxiliary steam boiler in the Installation. The CO_2 is captured, separated and transported off-site for permanent geological storage.

3.1.9 The key performance parameters for the proposed LCH technology are summarised in Table 3 below.

Table 3. Key Performance Indicators

Parameter	Description	Unit	H_2 Production BAT Value for GHR+ATR+PSA	JM Data fo H2TS Case B (1)
Process /Energy Efficiency				
Electrical Power Consumption	MJ / kg H_2 (after electrical power generation)	MJ/kg H_2	8.8	7.5(2)

Parameter	Description	Unit	H_2 Production BAT Value for GHR+ATR+PSA	JM Data fo H2TS Case B (1)
Overall Energy Conversion	Energy content of H_2 product (LHV) / overall energy input (LHV including power import)	%	76.1	74.4
Carbon Capture				
Total CO_2 Capture Efficiency	kg C captured /kg C in feed gas	%	95 - 97	97.1

3.1.10 The chosen LCH technology is reviewed further against the Environment Agency "Emerging Techniques for Hydrogen Production With Carbon Capture"(ETHPCC)[(1)] document in the sections to follow. Comment is provided as appropriate on the plant design basis and further designs to be completed which will be aimed at optimising both environmental and energy efficiencies.

3.1.11 Reference will be made to the following European Union BAT Reference Documents (BRef) and BAT Conclusions (BATc) where specific detail is not provided in, or is referred to, in the Emerging Techniques guidance:

- BRef(3) and BAT Conclusions(4) for Large Combustion Plant (BATc-LCP)
- BRef(5) and BAT Conclusions(6) for the Refining of Mineral Oil and Gas (BATc-O&G);
- BRef(7) and BAT Conclusions(8) for the Common Waste Water and Waste gas Treatment/ Management Systems in the Chemical Centre (BATc-WWWG); and
- BRef(9) and BAT Conclusions(10) for Common Waste Gas Management and Treatment Systems in the Chemical Sector (BATc-CWG).

3.1.12 No further consideration will be given to other H_2 production technologies in the sections to follow.

3.1.13 Specific option analysis will not be taken in a number of areas, including:

- Planned discharges to groundwater from the Installation, as none is planned. However, measures to prevent accidents that could lead to such emissions and associated controls to mitigate environmental consequences will be considered; and
- Direct releases of solid and liquids wastes from the Installation to land within the Installation boundary, as wastes will be sent offsite for treatment, reuse, recycling, recovery or disposal.

4 PLANT DESIGN AND OPERATION

4.1.1 Reference has been made to the Emerging Techniques guidance for this section.

Table 4. BAT for Plant Design and Operation

BAT No.	BATc Requirements	Demonstration of BAT – Operator Response	Operating to BAT?
3.1	**Flexible Operation** You must consider whether your hydrogen production plant may need to operate on a flexible basis to balance variations in demand from hydrogen users. You should consider whether this need for flexibility will affect the design, operation and maintenance of the plant. You should identify flexible operating scenarios where environmental performance could be affected, or where additional emissions are expected. For example, these could be as a result of rapid changes in capacity, or start-up following enforced shutdown. You should describe measures you would take to minimise the environmental impact of these scenarios, which could result in, for example: • reduced CO_2 capture rates • reduced energy efficiency • increased emissions to air, venting and flaring • increased effluent or wastes produced • increased risk of accidents in non-steady state conditions	• The LCH technology is flexible to meet varying demands from hydrogen users. An LCH plant can be started up over 12 – 13 hours and can be also ramped down from 100% to 40% in 10 minutes. • The rate of change in production is to ensure the plant operates within licensor stipulated guidance to maximise equipment integrity. • During this transient phase, the CO_2 capture rate will be maintained at 95% as a minimum, energy efficiency will remain high, no increased flaring, emission and effluent is expected. • As the change in plant rate is automated and trip points remain the same, no increased risk in accidents is expected. • Hydrogen storage is being engineered to provide a buffer in case the hydrogen production plant is tripped, in order to allow offtakers enough time to fuel switch from hydrogen to natural gas. • The nominations process for disposal of carbon dioxide is also being considered as part of the storage design, to ensure that as rates at offtakers are changed, carbon dioxide disposal is available.	Yes

BAT No.	BATc Requirements	Demonstration of BAT – Operator Response	Operating to BAT?
3.2	**Reliability and Maintenance** You will need to identify equipment and systems that are critical in avoiding emissions. You will need to design, operate and maintain these to make sure they are reliable and available, including providing installed back-up equipment, where necessary.	• The H_2 production plant is designed with an availability of at least 96.5%. The availability takes account of both planned and unplanned maintenance across the Installation. The plant is designed so that no planned outage is greater than 28 days from H_2 off to H_2 on (i.e. major overhaul that occurs every 4 years). • Continuous emissions monitoring systems (CEMs) and back-up CEMs will be installed for each phase to the relevant monitoring certification scheme (MCERTs or equivalent) standards. • The maintenance strategy will use established methods such as Risk Based Inspection (RBI) and Reliability Centred Maintenance (RCM). It is anticipated that an Integrated Operations and Maintenance (O&M) Team will have the responsibility for daily operations, including troubleshooting and effecting minor plant repairs. Major maintenance activities will be outsourced and/or serviced by the original equipment manufacturers. • All major maintenance activities requiring significant outages will be coordinated to occur during the planned routine turn around (TAR). Equipment requiring routine maintenance outside of this timeframe that cannot be taken offline without disruption to operation, will be spared and sited with sufficient isolation to facilitate the activity whilst plant production continues. • There will be sequences for startup and shut down to minimise operator intervention and standardised start up and shut down procedures.	Yes
	You should implement a risk-based other than normal operating conditions (OTNOC) management plan, which identifies potential scenarios, mitigation measures, monitoring and periodic assessment.	• The plant and associated control systems will be designed to minimise the potential for OTNOC events to occur. The plant will be operated using an automated control system to continuously monitor the operation of the plant and equipment at the site. Any non-conformance or deviation in normal operating parameters is expected to be identified by the automated control system. The control system will be designed to provide warnings to operators of undesirable deviations from normal operating conditions. The system will be designed to alert operators and provide sufficient time for them to take action to avoid OTNOC events. • Site operators shall be trained to monitor plant operation and take appropriate action(s) in the event of a potential OTNOC event being identified. Start up and Shutdown procedures shall be put in place with the aim to minimise the time during which the plant is operating at non-optimal conditions and operators shall be trained in the appropriate actions required should the potential for an OTNOC event be identified.	Yes

BAT No.	BATc Requirements	Demonstration of BAT – Operator Response	Operating to BAT?
		• All plant and equipment at the site will be regularly maintained including those systems provided to minimise the potential for OTNOC conditions to occur. • The Installation will also have accident management plan (AMP) and emergency response procedures for the management of spills, firewater, and the blocking of any discharge outlet to the river.	
3.3	**Overall CO_2 capture efficiency** You should design plant to maximise the carbon capture efficiency. As a minimum, you should achieve an overall CO_2 capture rate of at least 95%, although this may vary depending on the operation of the plant. You should consider how you would comply with future requirements for increased CO_2 capture efficiency by making your plant decarbonisation ready. You should plan to allow for space and technical retrofit within the design for additional carbon capture plant. This will allow for the capture of residual emissions of CO_2, for example, from combustion of any hydrogen purification residual gas.	• The proposed Installation is designed to deliver a carbon capture rate of 95% in accordance with current BAT guidance and has the potential capacity to further increase the capture rate to 97.1% to meet potential future regulatory changes. • All of the CO_2 is within the product stream and is therefore at high pressure and high concentration meaning it can be removed using industry standard CO_2 removal techniques; • The operation of the ATR at high temperatures, minimises methane slip and hence CO_2 emissions. • Tail gas from the pressure swing adsorption (PSA) is combusted to raise steam to be used in the process; and • Utilisation of a highly efficient Isothermal Shift (ITS) convertor maximises the reaction conversion and therefore minimises the CO slip and CO_2 emissions when the tail gas is combusted.	Yes
3.4	**Process CO_2 capture from hydrogen product** Technology for CO_2 capture from hydrogen product will typically be through absorption in a circulating solvent, with regeneration of the solvent through reducing pressure and heating to liberate CO_2. You should select the solvent, process design and operating conditions that maximise energy efficiency, capture performance, and minimise the waste and effluent treatment required. Where you have considered various options, you should provide the reasoning behind this to demonstrate that your chosen option uses overall BAT.	The CO_2 absorber is situated downstream of the Low Temperature Shist (LTS) reactor and will remove CO_2 in the syngas using an amine solution as the adsorber, with the treated gas being sent to the PSA. This will mean that the concentration of CO_2 will be < 0.1% mol in the syngas sent to the PSA and the concentration of CO_2 will be >95% in the CO_2 compression units.	Yes

BAT No.	BATc Requirements	Demonstration of BAT – Operator Response	Operating to BAT?
3.5	**CO_2 capture for steam methane reforming** In SMR, heat for the reformer reaction is provided by external combustion in a furnace. The plant could be designed in such a way that no post combustion capture is needed if both of these apply: • hydrogen is used as the fuel gas for the reformer • there is in-process CO_2 removal prior to hydrogen purification You will need to justify the best overall approach, considering all environmental impacts.	• Not Applicable – not using SMR technology	-
3.6	**CO_2 capture from residual gas from hydrogen purification** You should consider how to capture CO_2 produced by the combustion of residual gas, which results when hydrogen is purified. You should aim to remove this CO_2 to maximise the overall carbon capture efficiency and to make sure you achieve at least 95%. The residual gas may contain methane, carbon monoxide (CO) and CO_2 as well as hydrogen, nitrogen and argon. This is normally used as a fuel gas and any carbon containing compounds will be converted to CO_2. The amount of carbon-containing compounds depends on the efficiency of conversion and removal before the hydrogen purification stage.	• Overall CO_2 capture has been maximised. The proposed Installation is designed to deliver a carbon capture rate of 95% in accordance with current BAT guidance and has the potential capacity to further increase the capture rate to meet potential future regulatory changes. • As explained above, the siting of the CO_2 absorber downstream of the LTS convertor results in CO_2 being removed to < 0.1% mol in the syngas entering the PSA for H_2 purification. • The PSA has been designed to remove impurities from the syngas stream and bring the H_2 to export specification. The residual gas (tail gas) will be used as a decarbonised fuel for the auxiliary steam boilers. A portion of the tail gas is recycled back to the front end improving process efficiency. • The tail gas typical composition in mol % is presented below.	Yes

Parameter	End of Life
Methane:	5.5
Hydrogen:	79.7
CO:	3.1
CO_2:	0.05
N_2:	10.9
H_2O:	0.3
Methanol:	0.02
Ammonia:	0.02

BAT No.	BATc Requirements	Demonstration of BAT – Operator Response	Operating to BAT?
		Argon | 0.5	
3.7	**Energy Efficiency, Process Efficiency and Cooling** You should choose your hydrogen production process and design your plant to maximise: • energy efficiency (minimise the energy needed to produce each tonne of hydrogen) • process efficiency (minimise the raw materials, such as methane and water, needed to produce each tonne of hydrogen) To decide on BAT, you will have to balance how you achieve these efficiencies in order to optimise the environmental and economic requirements. You must explain how you have done this and what your considerations were. This should take into account all of the chemical and physical processes within the installation boundary needed to produce hydrogen and capture carbon. You should consider: • electrical power needs and whether you will import or generate on site • high pressure steam need and availability • maximising any residual waste heat recovery • cooling needs • cooling type and medium You should also consider: • heat integration optimisation, for example, heat recovery at: • higher temperatures from compression systems including the ASU, CO_2 and hydrogen compression for power generation or drives	• There will be a small amount of power generated on site by a hydraulic turbine in the CO_2 removal section and consumed by the process. Remaining power needs are met through import from the national grid., • During normal operation the auxiliary steam boilers will be operated with tail gas from the PSA as the fuel. • The LCH technology requires a significant amount of steam to be added to the natural feed gas – approximately 80% of this is raised and recovered for use from the process. The remaining 20% is generated in the auxiliary steam boilers. • Using the steam from the saturator and ITS convertor is more efficient in terms of quality, when compared to an SMR which typically uses the 860^{O}C stream at the exit of the reformer to raise medium pressure steam thereby degrading the quality of the heat. The LCH technology is therefore more efficient with an energy efficiency of 80.5% (LHV basis) than an SMR at 73.3% efficiency. • The use of the GHR allows heat to be recovered at significantly higher temperatures than an SMR which allows the LCH technology to use around 10% less natural gas for every unit of H_2 produced. • The LCH technology utilises a GHR-ATR combination which reduces the combustion requirements of ATR in isolation. This maximises the energy recovery within the process and due to reduced combustion requirements requires less O_2. This improved feedstock and O_2 utilisation therefore results in higher process efficiency. • In terms of heat integration, the process is designed using engineering techniques to evaluate process heat flows and optimise the overall energy use.	Yes

BAT No.	BATc Requirements	Demonstration of BAT – Operator Response	Operating to BAT?
	• medium temperatures for solvent recovery • lower temperatures for boiler feed pre-heat		
3.8	**Oxygen Production** Oxygen is required for the ATR and POX processes. It is usually produced by an ASU, which is a relatively large energy user. You must consider heat recovery from the heat generated by the air compression system and whether you can use it within the rest of the hydrogen production process to maximise energy efficiency. We expect you to explore all opportunities for waste heat recovery as the ASU will be considered part of the installation. You should take the following into account when designing the oxygen production plant and optimise to show you are using BAT: • overall energy consumption depends on the design of the ASU and its air compressor • energy required will be a balance between oxygen purity, oxygen pressure needed to supply the hydrogen production process and energy needed to purify the hydrogen • higher oxygen purity will increase the energy required for oxygen production, but reduce the amount needed for hydrogen purification to remove residual argon and nitrogen • co-production of argon and nitrogen can be used for export or on site • heat energy needed to dry and purify the compressed air	• Heat recovery and integration has been addressed as outlined 3.7 above. • In relation to provision of O_2 and N_2 there are two options being considered: a) inclusion of an ASU in the process train for O_2 production with associated storage of N_2 onsite as a back-up during Phase 2; and b) O_2 supply from a 3rd party which has operated an external ASU with long history of very high availability. This is the preferred baseline option for Phase 1. • Liquid nitrogen storage will be provided in the Installation to ensure the hydrogen plant can be safely shutdown and start-up. Other uses of N_2 is for purging equipment to free it from flammable / toxic material; blanketing amine storage and other storage tanks, compressor seals and sump vessels.	Yes

BAT No.	BATc Requirements	Demonstration of BAT – Operator Response	Operating to BAT?
	• options to increase the compressor exit temperature to improve options for heat recovery should be explored, balanced with compressor design and higher power requirement. • safe and reliable operation of both the ASU and hydrogen production plant where heat integration is used • high availability of oxygen supply and backup supply or liquid storage is important to avoid potential environmental impacts of emergency or frequent shutdown and start-up of the plant		
3.9	**Water Supply and Use** Water supply and its efficient use is an important aspect of BAT in hydrogen production plant. The quality of the water supply will determine the pre-treatment needed before it can be used as a: • raw material in hydrogen production • heat transfer medium • cooling medium Water is consumed in the process as part of the hydrogen product. Your choice of hydrogen production method will determine the ratio of hydrogen product that comes from water compared with that which comes from methane, or refinery fuel gas, or both. You should: • minimise the amount of water you use • segregate, treat and reuse water where possible • choose a cooling method that takes account of the temperature impact on process performance, energy efficiency and environmental impact on the receiving medium	• The anticipated raw water source will be from Northumbrian Water Ltd (NWL) raw water supply. • Raw water will be pre-treated prior to demineralisation in a raw water treatment plant which will include coagulation, flocculation, clarification, sludge dewatering, dissolved air flotation (DAF), ultrafiltration (UF) for removal of fine solids and filtration through a granulated activated carbon (GAC) filter. Further details are provided in Section 4.4 of the Supporting Statement (Document Reference: AP3328SQ-APP-SS). • Treated raw water will pass to the demineralisation plant which comprises two-stage reverse osmosis (RO) for the removal of ions and Electrodeionisation EDI to complete demineralisation process. The exact treatment package will be confirmed during FEED. • The selected LCH process has reduced fresh water consumption over other H_2 production techniques. • The opportunities for re-use and recovery of water within the process will be determined at FEED stage, but are anticipated to include: a. Steam system condensate through the demineralisation plant; b. Recovery of water from the effluent treatment plant; and c. Recovery of process condensate and flare knockout liquid through a bio-treatment plant. d. Segregation of different effluent streams – oily water, stormwater and process effluents	Yes

BAT No.	BATc Requirements	Demonstration of BAT – Operator Response	Operating to BAT?
		e. Consideration of Hybrid Cooling Towers – if those can meet other project criteria such as energy, economics & noise f. Use of stormwater to reduce freshwater abstraction g. The LCH GHR-ATR optimises use of water in the saturator by recovering the process condensate and minimising the amount of blowdown sent to the effluent plant.	
3.10	**Water Treatment** Water is condensed both from steam systems and from process cooling. In most cases, this water can be reused without being treated. However, some water will need to be removed to avoid the build-up of contaminants. You will need to treat it in an effluent treatment system before releasing it into the environment. You should decide how much water to treat and how to treat it before it is: • reused • released to surface water or sewage undertaker • disposed of You should identify how much contaminant, such as methanol and ammonia, needs to be removed and design the treatment process accordingly. You should identify any emissions to air or wastes that may result from the water treatment process, for example, emission of CO_2 from deaeration of boiler feed water.	• Opportunities for re-use and recovery of water within the process are outlined in the response to 3.9 above and these will be optimised and finalised at FEED stage. • The anticipated waste streams from the pre-treatment of water include: a. Water treatment sludge from pre-treatment plant and b. Bio-sludge from the bio-treatment plant. The above waste streams will be removed to a suitably licenced facility for treatment • Liquid Effluent Rejects from the effluent treatment plant .will be disposed of via pipeline to a discharge point in the Tees Bay.	Yes
3.11	**Feed Quality and Gas Treatment** Your choice of supply of methane-containing feed gas will determine the type of gas treatment processes you will need prior to the main conversion reactions., It will also determine whether you will need to remove inert gases at the hydrogen purification stage. If you use refinery fuel gas as your feed gas supply, where possible, you should remove contaminants such as sulphur and mercury in existing upstream refinery processes, taking account of BAT across the refinery installation.	• The site will utilise natural gas from the National Transmission System (NTS) as the feedstock for the process which for practical purposes will only contain low level of sulphur permitted by regulations. The use of gas from NTS will minimise the presence of contaminants otherwise present in refinery fuel gas. • The incoming gas stream will be pre-treated to remove sulphur species to less than 50 ppb. See Supporting Statement section 4.3 for further details. • Sulphur removal is carried out in two stages. A hydrodesulphurisation reaction to convert organic sulphur compounds to H_2S over a nickel/molybdenum catalyst and	Yes

BAT No.	BATc Requirements	Demonstration of BAT – Operator Response	Operating to BAT?
	You will need to take account of the possible range of gas composition so that you can design your processes to minimise the overall environmental impact, including substances such as: • sulphur (S), typically as H_2S • nitrogen (N_2) • CO_2 • mercury • other hydrocarbons You will need to design your gas treatment and downstream processes in order to: • minimise solid wastes (for example, catalyst) for recycling or disposal • minimise sulphur dioxide (SO_2) emissions to air where feed gas is combusted • maximise overall process reaction and energy efficiency • minimise emissions to air associated with the removal of nitrogen or other inerts You should consider removing sulphur compounds by hydrogenation and using catalyst adsorbent to avoid SO_2 emissions from combustion and catalyst poisoning. You should consider removing other hydrocarbons by pre-reforming to avoid carbon deposition on catalysts. You should remove mercury to avoid catalyst poisoning and other downstream contamination. Any CO_2 in the feed gas will be removed along with the CO_2 produced in the process. You should include this in the	then desulphurisation reaction where the H_2S is removed using a zinc oxide based catalyst. • The achievement of ultra-low levels of sulphur avoids catalyst poisoning and reduces emissions of SO_2.	

BAT No.	BATc Requirements	Demonstration of BAT – Operator Response	Operating to BAT?
	overall CO_2 balance and capture efficiency monitoring and reporting.		
3.12	**Reforming and CO Shift** Hydrogen is produced in the reforming and CO shift stages of the plant. You should convert methane to hydrogen, CO and CO_2 in the reforming stage, while minimising unreacted methane. You should optimise CO conversion to CO_2 considering the overall CO_2 capture requirement and the impact on downstream processing stages to meet the hydrogen product specification.	• H_2 will be produced in the GHR-ATR reforming section and the syngas from this reforming section will be passed to the CO conversion process which uses ITS and LTS reactors to maximise conversion to H_2 and CO_2.	Yes
3.13	**Reforming** You should select, design and operate the reformer reaction in order to: • reduce the risk of carbon deposition on catalyst, which would result in reduced reaction efficiency • minimise catalyst change frequency and the need for recycling or waste disposal If you choose ATR or POX technologies, carbon formation may be more likely due to the reducing atmosphere. You should choose operating parameters to minimise this risk.	• Soot formation will be minimised by optimising the steam to carbon ratio in the GHR-ATR stage and achieving the associated reaction of the hydrocarbons. The presence of soot particles will be monitored for in the process condensate.	Yes
3.14	**CO Shift** You should select, design and operate CO shift reaction in order to: • maximise energy efficiency through, for example, heat integration with the overall hydrogen production and CO_2 capture processes • minimise the duration of start-up operations and associated emissions to air from flaring • minimise the production of wastes for recycling or disposal	• The LCH utilises ITS and LTS reactors with copper-zinc-alumina catalyst to maximise the CO shift reaction. • There is process heat recovery from the hot syngas leaving the ITS prior to entering the LTS. • No chromium catalyst will be used. • Spent catalyst will be sent offsite for recovery rather than disposal.	Yes

BAT No.	BATc Requirements	Demonstration of BAT – Operator Response	Operating to BAT?
	You should consider a single step CO shift process rather than a more conventional high temperature or low temperature shift process, with isothermal conditions achieved through reactor cooling with recovery of heat. By using this option, it may allow you to: • increase overall heat integration and efficient use of recovered heat, as long as sufficient conversion of CO to CO2 is achieved • avoid using chromium catalyst needed for high temperature shift, therefore minimising hazardous waste • reduce the potential for catalyst damage, methanation reactions, and Fischer-Tropsch reactions • reduce the potential for the production of methanol which would condense out with water downstream and need to be treated by effluent treatment • consider the cost and environmental benefits of an isothermal reactor against a more complex multi-tube boiling water-cooled reactor		
3.15	**Catalyst Selection** When you choose which catalysts to use, you should consider the overall environmental performance, including, for example: • any required pre-treatment to avoid poisoning, to minimise waste and associated treatment • preventing any dust emissions, where applicable • the ability to recover or recycle the solids or metals from the spent catalyst waste • handling spent catalyst for environmentally safe recovery, recycling or disposal	• Catalysts have been selected to optimise the process efficiency while ensuring pre-treatment processes have been included which will avoid catalyst poisoning (see AP3328SQ-APP-SS Supporting Statement, Section 4.8 for further detail). • Natural gas will be desulphurised to prevent reforming catalysts from poisoning. • Shift catalysts will be reduced in situ prior to start-up. • Spent catalysts will be replaced by an appointed competent contractor on a frequency of 48 – 60 months dependant on the catalyst. This will tie in with planned preventative maintenance on the plant and will reduces the volume of spent catalyst generated to a specific period rather than a continuous waste production., This material will be sent for recovery/recycling.	Yes

BAT No.	BATc Requirements	Demonstration of BAT – Operator Response	Operating to BAT?
3.16	**Hydrogen Product** you will need to purify and compress hydrogen so that it is fit for purpose after it is separated from the CO_2 in the CO_2 capture stage. You should take account of hydrogen purification requirements. These will depend on: • the hydrogen product quality specification • impurities in the hydrogen following reforming, CO shift and CO2 capture steps The impurities may include: • CO, which is not converted to CO_2 in the reforming or CO shift sections • CO_2, which is not removed in the CO_2 capture section • methane, which is not converted to CO in the reforming section • nitrogen and argon – inert gases present in feed gas or oxygen supply • water – the hydrogen is saturated with water following CO_2 capture You should consider pressure swing adsorption (PSA) to remove impurities from the hydrogen. Treating residual gas containing the impurities is considered in section 3.6 CO_2 capture from residual gas from hydrogen purification. You should consider whether methanation to convert CO into methane is appropriate, depending on the specification of hydrogen, to make sure hydrogen is fit for purpose. You should consider the impact on overall energy efficiency and the need for further treatment of hydrogen purification off-gas streams.	• The LCH technology can provide H_2 with a minimum purity of 98 mol%. • The process will employ a PSA which will be designed to produce a high purity hydrogen stream and bring it to export specification for a range of operating cases. • No carbon species and water are expected to be in the export hydrogen. Therefore, users of the hydrogen will not emit any carbon dioxide. • The tail gas from the PSA unit will be used in the auxiliary steam boiler as a fuel source, no further treatment of the tail gas is required. • No methanation step is proposed as the CO will be removed using the PSA.	Yes

BAT No.	BATc Requirements	Demonstration of BAT – Operator Response	Operating to BAT?
	You should design the overall process to minimise the power required for compression to achieve the pressure required by the user. See section 3.7 energy efficiency, process efficiency, cooling.		
3.17	**CO2 Product** You should design the process to meet the required CO2 quality specification, temperature and pressure as required for transport to permanent geological storage. You should design the overall process to minimise the power required for compression to achieve the pressure required by the user. You should maximise recovery of waste heat from compression. See section 3.7 energy efficiency, process efficiency, cooling.	• The CO_2 produced will be removed from the gas via contact with an amine-based solvent, which will absorb (capture) the CO_2. The solvent will then be further regenerated to yield a CO_2 stream that will be compressed to medium pressure, dehydrated, and then exported to the NEP compression infrastructure on the NZT site to the east of the Main Site. • The process condensate from the CO_2 compression will be reused as boiler feedwater for the reforming process.	Yes

5 EMISSIONS TO AIR

5.1.1 BAT is to eliminate, minimise or reduce any emissions to air that could cause pollution which is discussed in the section to follow. A detailed air dispersion assessment has been completed (see Supporting Statement, Appendix F) to demonstrate the impact from the processes is not considered significant.

5.1.2 In terms of the specific BAT considerations, reference has been made to the Emerging Techniques guidance as summarised in Table 5 below.

Table 5. BAT for Emissions to Air

BAT No.	BATc Requirements	Demonstration of BAT – Operator Response	Operating to BAT?
4.1	**Combustion Processes** You should maximise energy efficiency and heat integration, so you minimise the need for combustion processes, resultant CO_2 and other combustion products. You should maximise the capture of CO_2 from combustion processes, taking account of the overall carbon capture requirement. If you decide that carbon capture from a combustion process is not appropriate, you must justify your decision based on BAT. You must identify and minimise the continuous and periodic emissions of combustion products to air. You should consider NOx abatement techniques where the combustion of hydrogen-rich gas with the potential for higher flame temperatures will increase thermal NOx formation, including: • burner design • flue gas recirculation • heat exchange with fuel or air You should consider whether abatement of any of these emissions is required to comply with relevant BAT AELs or local air quality standards, for example, for NOx. Where relevant, you should consider the following abatement techniques: • selective catalytic reduction (SCR)	• The Installation design optimises energy efficiency and heat integrations as outlined in the response to 3.7 in Table 4. • The proposed Installation is designed to deliver a carbon capture rate of 95% in accordance with current BAT guidance and has the potential capacity to further increase the capture rate to 97.1% to meet potential future regulatory changes. • With regards to NOx formation the main sources of this are related to use of the fired start-up heaters the auxiliary steam boilers and the flares. The flares are discussed in the response to 4.3 below. In relation to NOx control for the fired heaters and the auxiliary boilers the controls employed include: a. Use of a Distributed Control System (DCS) which will monitor and optimise combustion in both the pre-heaters and the auxiliary boilers. b. Use of low NOx burners in both the pre-heaters and the auxiliary boilers. c. Feed gas is heated before it enters the GHR preheater. d. The auxiliary steam boilers are also equipped with SCR which is used to reduce NOx during in normal operations when tail gas is used in the auxiliary boilers.	Yes

BAT No.	BATc Requirements	Demonstration of BAT – Operator Response	Operating to BAT?
	• selective non-catalytic reduction (SNCR) You should consider: • the overall impact of using residual gas from the hydrogen purification process as a supplementary fuel for fired equipment to balance overall heat requirements, while considering the impact of the additional emissions of combustion products to air • for ATR, whether the relatively smaller additional heat need can be supplied by combustion of hydrogen-rich residual gas or combustion of hydrogen product • the impact on emissions to air due to variability in fuel gas composition or any need to switch between fuel gas sources, for example, at start-up when residual PSA gas for fuel is not available and some feed gas may need to be combusted • You could consider using excess oxygen, where available, to support oxy-combustion, in order to remove the source of nitrogen and therefore limit thermal NOx formation. • Fuel NOx may form from nitrogen in the residual gas from the PSA. There is limited experience of using oxygen, especially for hydrogen-rich gases and any such proposal would need to be fully justified with supporting data. • You should design combustion processes to comply with required emissions limit values (ELVs) from the existing sources of statutorily applicable emission limits and BAT AELs, including the following: a) Medium Combustion Plant Directive b) Industrial Emissions Directive Chapter III Annex V ELVs c) BAT AELs identified in the Large combustion plant BREF and BATC d) Refining of Mineral Oil and Gas e) Large Volume Inorganic Chemicals – Ammonia, Acids and Fertilisers	• The site will also recirculate H_2 rich tail gas from the PSA during normal operations where it will be the fuel for the auxiliary steam boilers. The tail gas composition has low concentration of nitrogen present coupled with the higher flame temperatures means that NO_x formation will be lower than with natural gas, however. the change in flue gas volume when using tail gas needs to be considered and as such provision has been made to facilitate the use of SCR during normal operations. • In relation to the fired start-up heaters the net rated thermal input means they are classed as medium combustion plant (MCP). However, as they only operate during start-up, the overall annual runtime of each will be <500 hours and as such no emission limit values will be applied. • For the auxiliary steam boilers, the rated thermal input means that Large Combustion Plant will apply and as such BAT-AELs were reviewed and it can be confirmed that: a. The auxiliary steam boilers operate on natural gas during start-up and no emission limit values apply during start-up conditions. b. No BAT-AELs are specified for combustion of a hydrogen rich fuel in the LCP although there are BAT-AELs for using process generated fuels c. Emissions from the auxiliary steam boilers will be less than 80 mg/Nm^3 for NOx as a long term average with potential short term peaks to 110 mg/Nm^3. It is proposed that NOx ELVs set for the boilers are in line with the emerging guidance "Emission Limit Values (ELVs) for Hydrogen Combustion Plant Greater than 1 megawatt thermal input". This guidance indicates that correction factors should be applied to natural gas ELVs to account for changes in flue gas volume when using H_2-rich fuels. The correction factor for gas streams at >95% H_2 content would be 1.37 or 137% of the natural gas ELV. The proposed NOx ELVs for	

BAT No.	BATc Requirements	Demonstration of BAT – Operator Response	Operating to BAT?
	f) Common Waste Water and Waste Gas Treatment/Management Systems in the Chemical Sector	the plant would therefore be 82.2 mg/Nm^3 yearly average and 116.45 mg/Nm^3 daily average.	
4.2	**Post Combustion Carbon Capture (PCC)**	- PCC is not utilised on site	N/A
4.3	**Flaring** You must design and operate your plant to minimise the need for continuous or intermittent flaring or venting of gases, whether for operational or safety reasons, including: - methane or refinery fuel gas - hydrogen - CO_2 This should include: - flaring rather than venting, where emissions cannot be eliminated and where practicable, to minimise emissions of higher global warming potential gases such as methane and hydrogen - plant design to maximise equipment availability and reliability (see section 3.2 Reliability and availability) - avoiding routine flaring for waste gas destruction - managing production of off-gas and balance against requirements for fuel gas using advanced process control, for example - using procedures to define operations, including start-up and shutdown, maintenance work and cleaning - using commissioning and handover procedures to ensure that the plant is installed in line with the design requirements - using return-to-service procedures to ensure that the plant is recommissioned and handed over in line with the operational requirements	- The Installation will be equipped with a DCS with appropriate control loops, set points, alarms and shutdown initiators. The role of the DCS will be to dynamically control the system within its' operating envelope or regime. This will minimise the occurrence of any unsafe deviations and will act as second layer of protection. A well designed DCS will make the incidence of plant trips rare. The alarm and trip summary shall include a record of the setpoint for every alarm, trip and permissive shown on the P&ID - A flare system will be provided for each phase and will be designed with sufficient capacity for all normal, abnormal and emergency operating conditions arising from Phase 1 and 2 combined. - The flares will be subject to planned preventative maintenance as described in the response to 3.2 in Table 4 above. - In operation the PSA hydrogen recovery will be optimised over the plant life to ensure that tail gas is not over-produced and be otherwise sent to flare - During normal operation, flaring of hydrogen will only be used for off-spec operational and emergency conditions. Otherwise the flares will operate in pilot mode Outside of normal operation, flaring will be used during start-up and for plant performance testing. - Flare design will be finalised during FEED but will be designed, fabricated and tested in accordance with appropriate standards (e.g. API standards or similar). - Procedures will be developed as part of the Environmental Management System (EMS) for flare start-up, operations, shutdown, maintenance and cleaning and flare operation will be monitored and controlled via the DCS control system to ensure:	Yes

BAT No.	BATc Requirements	Demonstration of BAT – Operator Response	Operating to BAT?
	• designing flaring devices to enable smokeless and reliable operations, and to ensure an efficient combustion of excess gases when flaring under other than normal operations • monitoring and reporting of gas sent to flaring and associated parameters of combustion You must minimise emissions under start-up, shutdown, and abnormal operations. This can be achieved by: • using a flare gas recovery system with adequate capacity • routing gas that would be flared to alternative users • using high integrity relief valves • other measures to limit flaring to abnormal operation	a. combustion is optimised. b. key parameters such as gas flow, temperature and pressures are monitored; and c. operation is smokeless. • The flare ignition system will be specified with built in redundancy and will meet or exceed API 537 requirements for wind speed and rainfall so that the pilot remains lit in adverse environmental conditions. Pilot gas will be supplied from a third-party reliable gas supplier through piped connection and failure of pilot gas from the source is unlikely. • Flare flame detection will be through retractable thermocouples with redundancy and indications will be provided on the flare ignition panel showing pilot status, with loss of pilot alarms provided to alert operators. CEMs will be used to continuously monitor the emissions from the flare, any deviation from the expected emission concentrations would indicate some issue with the flare and the Operator will be expected to take required corrective action immediately. • Records will be maintained via the Business Planning and Control System (BPCS) including recording of flaring events (i.e. combustion of process gases), the estimated gas composition, the volume of gas combusted and the duration of the flaring event. • The plant commissioning procedures will be developed in accordance with the bp system handover management process (SHMP). The SHMP is a stage gated process from factory dispatch through to handover to Operations. The purpose of the process is to validate completion and the technical integrity, which has been designed into the plant by Engineering, is demonstratively delivered through Commissioning activities.	
	Venting You should quantify and assess harm from other routine venting and purging requirements, identifying any pollutants that are expected to be present, including, for example:	• Sources of venting onsite will include: a. Steam vents (GHR steam jacket vent and ATR Steam jacket vent, operated continuously) and pressure relief valves on the steam system (only operated during abnormal operation	Yes

BAT No.	BATc Requirements	Demonstration of BAT – Operator Response	Operating to BAT?
	• CO_2 • hydrogen • CO • methane • ammonia vapour • methanol vapour	to reduce pressure in steam systems), giving rise to emission of demineralized water with very low concentrations of boiler treatment chemicals); b. Low levels of emissions from tank breathing losses associated with the storage of diesel for the operation of the emergency generator and fire water pumps, as well as from amine storage vessels c. While the majority of H_2 is managed through flaring some H_2 venting takes place for systems blowdown in an emergency (e.g. from compressors), in a non-emergency (e.g. start-up) and if an ASU is installed from the O_2 vent stream (for further details see section 5 of the Supporting Statement). d. Venting of CO_2 will be infrequent and only as required for safe operation of the plant. It will occur during scenarios such as spurious trips, emergencies, inspections and testing. An assessment of CO_2 venting has been completed and is presented in Appendix P of the Supporting Statement.	

6 EMISSIONS TO WATER

6.1.1 BAT is to eliminate, minimise or reduce any emissions to water that could cause pollution which is discussed in the section to follow. An assessment has been completed for potential discharges to water (see Supporting Statement, Appendix L) to demonstrate the impact from the processes is not considered significant.

6.1.2 In terms of the specific BAT considerations, reference has been made to the Emerging Techniques guidance as summarised in Table 6 below.

Table 6. BAT for Emissions to Water

BAT No.	BATc Requirements	Demonstration of BAT – Operator Response	Operating to BAT?
5.1	**Effluent Treatment Discharges** You should identify continuous and periodic effluent streams from the process and determine whether effluent treatment is required. These streams may include process condensate containing contaminants, which may need treatment before discharge, for example: • methanol • ammonia • CO2 • amines • degradation products You should treat water for reuse as far as possible. See section 3.10 Water treatment.	**Surface Water** • A suitable surface water drainage network and management system will be provided to segregate uncontaminated surface waters from those that could be potentially contaminated. • The drainage network will provide appropriate interception, conveyance, treatment and attenuation of surface water run-off, including: a. Clean stormwater may be recirculated to the raw water treatment plant or may be discharged to the Tees Bay. b. Clean surface run-off will be collected in a SuDs drainage system and discharge to controlled waters. c. Surface run-off within main process equipment areas will be segregated from main 'clean' surface drainage areas using kerbs, bunds and sumps. Contaminated surface water will be directed to the onsite effluent treatment plant. d. Effluents collected in the carbon capture area of the plant will be collected in a separate carbon capture closed drainage system and fully segregated from other effluents. The closed drainage system facilitates sampling of this effluent stream so that undegraded solvent can be reused	Yes

BAT No.	BATc Requirements	Demonstration of BAT – Operator Response	Operating to BAT?
		on the process and degrade solvent can be disposed via vacuum tanker for offsite disposal. **Process Wastewater** • Wastewater streams generated at the plant are anticipated to comprise process condensate, cooling tower blowdown, demineralisation plant rejects, flare knock out liquids and sanitary effluent. • Process condensate from the syngas plant, DAF waste, filtration waste and flare KO drum liquid will be treated in the biological treatment plant to facilitate recovery and reuse of this stream. • Water from the biological treatment plant will be sent through the raw water treatment plant to recover for use as feed water for the process. • Cooling water blowdown, DMW plant rejects and dewatering filtrate are treated in the Effluent Treatment Plant (ETP) followed by discharge via the NZT outfall (release point W1) to Tees Bay • Direct discharges to the NZT outfall will meet the BAT-AELs specified in the BREF for Common Wastewater and Waste Gas Treatment and Management Systems in the Chemical Sector.	

7 OTHER ISSUES IN EMERGING TECHNIQUES GUIDANCE

7.1.1 BAT for other issues specific to the Emerging Techniques guidance include waste, monitoring, unplanned emissions and accidents along with noise and odour. These are reviewed against the guidance and are summarised in Table 7 below.

Table 7. BAT for Other Aspects of Hydrogen Production

BAT No.	BATc Requirements	Demonstration of BAT – Operator Response	Operating to BAT?
6.0	**Waste** You must eliminate or minimise wastes and treat, where appropriate. Liquid wastes such as: • demineralised water production reject stream • amine solvent – for example, from bleed or feed replacement • dehydration solvent – for example, in case of tri-ethylene glycol dehydration • amine reclaimer residue Solid wastes such as: • depleted catalyst material – hydrogenation, reforming, CO shift • spent adsorbent materials – gas treatment, dehydration, hydrogen purification • solids from amine filtration • soot (POX process)	The plant will develop a Waste Management Procedure (WMP) prior to commencement of site operations, detailing the waste storage and handling procedures on site. The WMP shall outline identification of waste streams and how they must be handled, including appropriate segregation and storage within designated waste storage areas on site. The plant will apply the waste hierarchy for the management of any waste produced on site. It is expected that due to the inherent nature of the site operations and fuel used, the site shall only produce minor quantities of waste, primarily from maintenance. The main waste stream generated from the site activities is likely to comprise used lubricating oil, which will be sent off site for appropriately management via licenced contractors. In relation to spent catalyst material See Table 4 BAT No 3.15 regarding catalyst selection and reuse/recycle.	Yes
7.0	**Monitoring** The main purpose of monitoring is to demonstrate compliance with the permit and show that emissions from the process are not causing harm to the environment. You must also carry out monitoring to show that resources are being used efficiently. This includes: • energy and resource efficiency • carbon capture efficiency • verifying that the CO_2 product is suitable for safe transport and storage. • hydrogen product quality	Monitoring arrangements for the Installation are detailed in Section 6 of the Supporting Statement and covers: • infrastructure monitoring • process monitoring • emissions and compliance monitoring A commissioning plan will be prepared after FEED has been completed which will include the monitoring plan for this phase and which will incorporate a range of process and emissions monitoring as well as monitoring to support optimisation of the process including energy, resource and process efficiency. All monitoring	Yes

BAT No.	BATc Requirements	Demonstration of BAT – Operator Response	Operating to BAT?
	• verifying (when applicable) compliance with low carbon hydrogen standards Your permit application should include a monitoring plan for both a commissioning phase and routine operation. During commissioning phase, you will need to assess monitoring results and optimise the operation of the process. You will need to report on your commissioning phase monitoring results, your assessment of them and any changes you want to make to the operation. It's likely you will need to do more extensive monitoring during the commissioning phase than during routine operation. As these production techniques for hydrogen with CCS are emerging techniques, you will need to develop monitoring methods and standards. You should include proposals for this in your permit application. Complying with ELVs in your permit will provide the necessary protection for the environment, by monitoring emissions at authorised release points. You must also show that you are managing the process to prevent (or minimise) the formation of solvent degradation products. Where degradation products are formed (and may be released), you must reduce these and any solvent emissions to the appropriate level. This process control monitoring will also be part of the permit conditions.	systems will be commissioned and in service prior to the introduction of any hazardous process medium. A monitoring plan for the operational phase will be developed prior to the plant becoming operational and will be revised based on the outputs from commissioning.	
7.1	**Monitoring point source emissions to air** You should provide a monitoring plan for monitoring emissions to air, based on expected pollutants such as: • ammonia • amine compounds • SO_2 • NOx • CO • methane • hydrogen You should do this using appropriate methods and measuring techniques. Emissions of methane and hydrogen should be eliminated or minimised due to their global warming potential.	The flue gas from the site auxiliary boiler stacks will be monitored using MCERTS certified Continuous Emissions Monitoring Systems (CEMs) in accordance with EN 14181. This system will continuously monitor NO_x, CO and NH_3 (associated with SCR use) for the auxiliary boilers. No provision has been made for SO_2 or particulate monitoring as the fuel will be natural gas and H_2 rich tail gas. O_2, water, temperature and pressure will also be recorded. CEMS will also be used to continuously monitor the emissions from the flares. Periodic monitoring will be used to monitor the fired heaters, emergency generators and fire pumps as outlined in section 6.2 of the Supporting Statement. This is consistent with monitoring	Yes

BAT No.	BATc Requirements	Demonstration of BAT – Operator Response	Operating to BAT?
	Your monitoring should consider, for example: • NOx and CO emissions from combustion • SO_2 emissions from combustion where the fuel source contains sulphur • ammonia emissions where SCR or SNCR is used • amine or amine degradation products and other volatile solvent emissions, where relevant • methane and hydrogen 'slip' from any combustion processes • any other sources of methane or hydrogen emissions For combustion plant, your monitoring plan should demonstrate compliance with the applicable emission limits. Where you are using post-combustion CO2 capture, for example, using amine solvent, your plan should include monitoring relevant emissions such as: • ammonia • volatile components of the capture solvent • likely degradation products such as nitrosamines and nitramines Specific pollutants arising from post-combustion capture may be monitored by continuous emissions monitors, if they are available, or by periodic extractive sampling. Where aerosol formation is expected, the sampling must be isokinetic.	requirements for MCP which operate less than 500 hours per annum. A monitoring plan for the operational phase will be developed prior to the plant becoming operational and will be revised based on the outputs from commissioning. There is no post-combustion carbon capture.	
7.2	**Monitoring emissions to water** You must monitor emissions to water based on expected impurities (for example, ammonia, amine compounds, methanol, CO_2) using appropriate methods and measuring techniques. You should use monitoring standards for discharges to water following: • BATC for common wastewater and waste gas treatment/management system in the chemical sector • BATC for the refining of mineral oil and gas	Discharges of treated effluent to the Tees Bay will be monitored in accordance with relevant BS EN monitoring standards if this option is pursued. A Monitoring Plan will be in place to monitor discharges to water as per the relevant schedule in the Environmental Permit. This will be developed prior to the plant becoming operational and will be revised based on the outputs from commissioning. r	Yes
7.3	**Monitoring standards** The person who carries out your monitoring must be competent and work to recognised standards such as the Environment Agency's monitoring certification scheme (MCERTS). MCERTS sets the monitoring standards you should meet. The Environment Agency recommends that you use the MCERTS scheme,	Monitoring will be carried out in line with the scheduled monitoring detailed in the EP using the relevant MCERTS or equivalent standards in an accredited laboratory.	Yes

BAT No.	BATc Requirements	Demonstration of BAT – Operator Response	Operating to BAT?
	where applicable. You can use another certified monitoring standard, but you must provide evidence that it is equivalent to the MCERTS standards. There are no prescriptive BAT requirements for how to carry out monitoring. Monitoring methods need to be flexible to meet specific site or operational conditions. You must use a laboratory accredited by the United Kingdom Accreditation Service (UKAS) to carry out analysis for your monitoring. You should also refer to the JRC Reference Report on Monitoring for IED Installations		
7.4	**Monitoring CO_2 capture performance** You should clearly identify how you will monitor the CO_2 capture performance of the plant. The regulators expect you to monitor CO_2 capture performance according to standards that are recognised under the UK ETS. Measurements required to monitor CO_2 emissions to atmosphere may, for example, include directly measuring the flow and composition of fuel gas to combustion systems. This, together with measuring the following, will allow monitoring of the CO_2 capture rate and CO_2 quality (considering any impurities that could impact downstream systems): • flow and composition of feed gas. • hydrogen product (including methane content where applicable) • CO_2 product streams You will need to include: • CO_2 equivalent mass balance • CO_2 equivalent in feed gas • total capture efficiency (CO_2 equivalent captured as a mass percentage of CO_2 equivalent in feed gas) • CO_2 equivalent released to the environment. • CO_2 quality	The process will be monitored for: • Flow and composition of the feed gas. • Flow and composition of the H_2 product. • Temperature, pressure, and flow of CO_2 being exported. CO_2 capture performance will also be confirmed in accordance with standards recognized under the UK ETS.	Yes
7.5	**Monitoring process performance**	The Installation will be controlled and operated via a DCS to continuously monitor the operation of the plant and equipment at the	Yes

BAT No.	BATc Requirements	Demonstration of BAT – Operator Response	Operating to BAT?
	You should identify the main requirements for monitoring process operations where these ultimately impact on environmental performance, including, for example, for the CO_2 capture system: • amine system performance, including monitoring of amine solvent quality such as amine concentration • pH and presence of degradation or corrosion products • amine temperatures • amine and wash water circulation rates • rich and lean amine CO_2 loading • stripper reboiler steam rates You should monitor energy efficiency in the hydrogen production and CO_2 capture processes by measuring feed and product gas flows and electrical power consumption to calculate overall energy consumption. You should monitor the quality of the hydrogen product to ensure it is fit for purpose. Requirements for process performance monitoring, either online or offline, will also be a condition of the permit.	site including key process parameters such as emissions, flue gas flow, flow, temperatures and pressures. Any non-conformance or deviation in normal operating parameters will be identified by the DCS to allow the operator to take action to avoid a breach of permitted emission levels Process and operational performance will be detailed in EMS procedures which will include: • equipment condition monitoring; • periodic inspection and testing of systems; • functional testing of all safety devices; • inspection and testing of devices according to company standards and the relevant Codes of Practice; and, • relevant Periodic Inspection and Test (PI&T) programme relevant to the plant are included in the operational procedures.	
8.0	**Unplanned emissions and accidents** You should propose a leak detection and repair (LDAR) programme that is appropriate for the fluids and their composition. This should use industry best practice to manage releases, including from joints, flanges, seals and glands. You should include how you will use LDAR to eliminate or reduce fugitive emissions of methane and hydrogen due to their global warming potential. Your hazard assessment and mitigation for the plant must consider the risks of accidental releases to the environment. This should also consider the actual composition of the liquids, gases and vapours that could be released from the plant after an extended period of operation.	Leak detection and management systems will be in place and the Operator will develop an appropriate LDAR Plan prior to the plant being commissioned. The Environmental Risk Assessment looks at the risks and impacts of unplanned emissions and accidents, The Supporting Statement also covers the management techniques for such events.	Yes
9.0	**Noise and odour** You need to consider sources that have high potential for noise and vibration. In, particular CO_2 and hydrogen compression, pumping and fan noise could be significant additional sources.	A Noise Impact Assessment has been produced to identify and assess potential noise sources taking into consideration the inherent mitigation built into the design. The assessment is presented at Appendix H of the Supporting Statement and concludes that noise is	Yes

BAT No.	BATc Requirements	Demonstration of BAT – Operator Response	Operating to BAT?
	Once you've identified the main sources and transmission pathways, you should consider using common noise and vibration abatement techniques and mitigation at source, wherever possible. For example: • embankments to screen the source of noise • enclosure of noisy plant or components in sound-absorbing structures • anti-vibration supports and interconnections for equipment • orientation and location of noise-emitting machinery • changing the frequency of the sound. Handling, storing and using some amines may result in odour emissions, so you should always use best practice containment methods. Where there is increased risk that odour from activities will cause pollution beyond the site boundary, you will need to send an odour management plan with your permit application.	not expected to create a significant impact. As such no Noise Management Plan is proposed at this time. Odour is assessed as part of the Environmental Risk Assessment (Appendix D of Supporting Statement) and is not expected to create a significant impact. As such an Odour Management Plan is not proposed at this time.	

8 ASSESSMENT OF STORAGE

8.1.1 The BRef document for Large Volume Inorganic Chemicals – Ammonia, Acids and Fertilisers (LVIC-AAF) was reviewed in respect of the storage and handling of materials such as amines – this directs that the BAT requirements for storage of such chemicals is defined within European Commission (2005). “BREF on Emissions from Storage”. The assessment against the BAT for storage is detailed below.

Table 8. BAT Assessment for Storage

BAT No.	BATC Requirements	Demonstration of BAT	Operating to BAT?
1	**Storage of liquids and liquefied gases** Tanks – General Principles to prevent and reduce emissions: a) Tank design b) Inspection and maintenance c) Location and layout d) Tank colour e) Emissions minimisation principle in tank storage f) Monitoring of VOC g) Dedicated systems	**Tank Design** Tank design for substances such as amine solvent, hydrogen and diesel is being developed to meet the relevant regulatory standards (i.e., environmental and safety) including CIRIA C736 requirements. Each tank design will be subject to HAZID and HAZOP studies and will consider: • The physico-chemical properties of the substances being stored; • Material of construction is suited to material properties; • The instrumentation and controls required at each tank, specific to the material stored; • The safety devices such as pressure relief devices, interlocks and containment; • The tank monitoring arrangements including alarms and associated control processes; • Access for maintenance and inspections; • Tank colour taking into consideration the liquid/vapour properties of each material; and • Potential emergency scenarios specific to the material being stored.	Yes

BAT No.	BATC Requirements	Demonstration of BAT	Operating to BAT?
		Inspection and Maintenance Each tank and its associated pipework will be included in the Planned Preventative Inspection and Maintenance PPIM) programme. PPIM includes a means of tracking the status of maintenance through to completion. Corrective work such as repairs or remediation required as a result of equipment fault, breakdown or degradation shall be recorded and managed in the same system. This will cover all equipment, plant wide. **Location and Layout** Tank locations are shown on the site layout plan. Each tank provides for above ground storage and will be located in well-ventilated areas. **Emissions Minimisation** Each liquid storage tank will be situated within a appropriately designed containment which will prevent releases to ground and water. Containment will be designed to CIRIA C176. **VOC Monitoring** An LDAR management plan will be developed for the site prior to plant commissioning. **Dedicated Systems** The installation will use dedicated storage systems for amines, diesel and ammonia solution for the SCR.	

BAT No.	BATC Requirements	Demonstration of BAT	Operating to BAT?
		See Supporting Statement.	
2	Tank specific considerations Fixed roof tanks	**Amine Tank** The amine tank will be nitrogen blanketed and flow rate in/out will be controlled by pressure control on the tank vapour space. The tanks will vent to atmosphere. Demineralised water is fed to the top of the absorber column to backwash the amine carry over. Vapur pressure of the amin solution will range from 0.0027 to 0.39 hPa as per the MSDS sheet.	Yes
3	Preventing incidents and (major) accidents: • Safety and risk management • Operational procedures and training • Leakage due to corrosion and/or erosion • Operational procedures and instrumentation to prevent overfill • Instrumentation and automation to detect leakage • Flammable areas and ignition sources • Fire protection • Fire-fighting equipment • Containment of contaminated extinguishant	**Safety and Risk Management** The site will be subject to COMAH regulation and processes/infrastructure including storage tanks will be subject to HAZID and HAZOP studies, development of a Safety Report and an Emergency Management Plan. The DCO application includes a Major Accidents and Disasters chapter in the Environmental Statement and the production of a COMAH Safety Report. **Operational Procedures and Training** Appropriate documented procedures will be implemented for environmentally critical plant, equipment and operations, whose failure could lead to adverse impact on the environment. These procedures will cover: • Operation of equipment;	Yes

BAT No.	BATC Requirements	Demonstration of BAT	Operating to BAT?
		• Maintenance of equipment; and, • Spill contingency procedures. Site staff will be subject to relevant training in respect of site procedures and operational control. **Leakage Due to Corrosion and/or erosion.** • The tanks will be designed with regards to the physico-chemical properties of the materials being stored and will be constructed of an appropriate material (e.g., concrete or steel). • Liquid storage tanks will be equipped with containment to retain any materials which may have leaked thus minimizing risk to ground or waters. • Each tank will be subject to routine inspection and maintenance. • Emergency response equipment will be serviced and maintained in accordance with requirements defined in the site major emergency procedure. Details of the maintenance tasks and compliance will be available on-site via the SAP System. • Backup systems will also be subject to regular maintenance as per operations standards. Mandatory tasks must be completed at a defined frequency where they are associated with regulatory, statutory, mechanical integrity or other procedural requirements.	

BAT No.	BATC Requirements	Demonstration of BAT	Operating to BAT?
		Operational procedures and instrumentation to prevent overfill/detect leakage The plant is undergoing best practice in the engineering design of process facilities and the specification of SIS Safety Instrumented Functions and safety lifecycle processes. These include appropriate design of systems to prevent overfill, a loss of containment occurring from process systems which could lead to an accident. Use of appropriate standards are a key mitigation measure in the prevention of a number of risk events, such as fire, explosion and toxic release. During Project operation and maintenance activities, detailed risk assessments will be completed, documented and regularly updated to reflect any changes made on site. These risk assessments will demonstrate a robust basis for safe operation of the Site as required by DSEAR. **Fire protection** The site will be subject to COMAH regulation and fire protection measures will be developed during the detailed design following HAZID and HAZOP studies. Details will be captured in the Site Safety Report and Site Emergency Plan. **Fire Fighting Equipment** • Portable fire extinguishers compliant with BS 5306 will be provided in accordance with installation guidance codes of practice.	

BAT No.	BATC Requirements	Demonstration of BAT	Operating to BAT?
		• Staff will be trained in the use of such equipment; • All extinguishers will be checked as part of the site inspection programme. • A manual system will provide firefighting water at strategic positions around the Site which will be specified in the detailed design. **Containment of Contaminated Extinguishant** Firewater will be managed via the site surface water drainage system which includes a fire water retention pond which can be isolated in the event of a fire to contain the firewater on site. See Supporting Statement and Environmental Risk Assessment (Appendix D).	
4	• <u>Transfer and handling of liquids and liquefied gases</u> • Inspection and maintenance • Leak detection and repair programme • Emissions minimisation principle in tank storage • Safety and risk management • Operational procedures and training	The controls outlined in No 3 are also applicable to the transfer and handling of liquids and liquifed gases.	Yes
5	<u>Considerations on transfer and handling techniques</u> **Piping** BAT is to apply aboveground closed piping in new situations.	Above ground pipelines will be utilized on site. The pipeline design will minmise the number of bolted flanges and gasket-sealed joints by replacing them with welded connections. Where bolted flange connections cannot be avoided, the operator will:	Yes

BAT No.	BATC Requirements	Demonstration of BAT	Operating to BAT?
		• fit blind flanges to infrequently used fittings to prevent accidental opening. • using end caps or plugs on open-ended lines and not valves. • ensure gaskets are selected appropriate to the process application • ensure the gasket is installed correctly • ensure the flange joint is assembled and loaded correctly • Use high integrity gaskets where appropriate. • Prevent internal corrosion by: a. selecting construction material that is resistant to the product b. applying proper construction methods c. applying preventive maintenance, and d. where applicable, applying an internal coating or adding corrosion inhibitors. External corrosion will be prevented by applying appropriate layers of a coating system where applicable depending on the site-specific conditions.	
6	Vapour treatment BAT is to apply vapour balancing or treatment on significant emissions from the loading and unloading of volatile substances to (or from) trucks, barges and ships.	If confirmed through FEED studies as being required, the amine storage tanks will have atmospheric fixed roof construction with appropriate abatement installed on breather vents, and suitable equipment to employ back-venting to tankers during filling, to minimise fugitive emissions and mitigated any odour emissions.	Yes
7	Valves BAT for valves include: • correct selection of the packing material and construction for the process application with	Valves will be finalised at FEED following HAZID and HZAOP studies and will be selected and installed to ensure	Yes

BAT No.	BATC Requirements	Demonstration of BAT	Operating to BAT?
	monitoring, focusing on those valves most at risk (such as rising stem control valves in continual operation). • applying rotating control valves or variable speed pumps instead of rising stem control valves • where toxic, carcinogenic or other hazardous substances are involved, fit diaphragm, bellows, or double walled valves • route relief valves back into the transfer or storage system or to a vapour treatment system.	valves are appropriate to the properties of the materials being handled.	
8	Pumps and compressors **Installation and maintenance of pumps and compressors** The design, installation and operation of the pump or compressor heavily influence the life potential and reliability of the sealing system. The following are some of the main factors which constitute BAT: • proper fixing of the pump or compressor unit to its base-plate or frame • having connecting pipe forces within producers' recommendations • proper design of suction pipework to minimise hydraulic imbalance • alignment of shaft and casing within producers' recommendations • alignment of driver/pump or compressor coupling within producers' recommendations when fitted • correct level of balance of rotating parts • effective priming of pumps and compressors prior to start-up • operation of the pump and compressor within producers' recommended performance range	Pumps and compressors will be finalised at FEED following HAZID and HZAOP studies and will be selected and installed to ensure: • Equipment is fixed to its base plate and/or frame; • Shafts, casings, drives and pumps will be correctly aligned; • Hydraulic and rotatingg systems are correctly balanced; • Equipment is selected to suit its duty and the materials being handled; • Equipment is operated and maintained in accordance with manufacturer's recommendations; and • Seals for pumps and compressors will be suitable for the material being handled.	Yes

BAT No.	BATC Requirements	Demonstration of BAT	Operating to BAT?
	• the level of net positive suction head available should always be in excess of the pump or compressor • regular monitoring and maintenance of both rotating equipment and seal systems, combined with a repair or replacement programme. **Sealing system in pumps** BAT is to use the correct selection of pump and seal types for the process application, preferably pumps that are technologically designed to be tight such as canned motor pumps, magnetically coupled pumps, pumps with multiple mechanical seals and a quench or buffer system, pumps with multiple mechanical seals and seals dry to the atmosphere, diaphragm pumps or bellow pumps. **Sealing systems in compressors** BAT for compressors transferring non-toxic gases is to apply gas lubricated mechanical seals. BAT for compressors, transferring toxic gases is to apply double seals with a liquid or gas barrier and to purge the process side of the containment seal with an inert buffer gas. In very high pressure services, BAT is to apply a triple tandem seal system.		
9	**Sampling connections** BAT, for sample points for volatile products, is to apply a ram type sampling valve or a needle valve and a block valve. Where sampling lines require purging, BAT is to apply closed-loop sampling lines.	No intrusive sampling is required for the products, there are sample lines linked to on line equipment and no operator intervention is required.	

9 CONCLUSION

9.1.1 On the basis of the assessment against the required BAT Conclusions, as shown in the preceding sections, it is considered that the proposed Installation will be designed and operated in compliance with the:

- Emerging Techniques for Hydrogen Production With Carbon Capture and in accordance with BAT ; and
- BREF on Emissions from Storage.

10 REFERENCES

1. Environment Agency, February 2023, Hydrogen Production With Carbon Capture: Emerging Techniques.
2. European Parliament and Council of European Union, November 2010, Directive 2010/75/EU on Industrial Emissions (Integrated Pollution Prevention Control).
3. European Parliament and Council of European Union, 2017, Best Available Techniques (BAT) Reference Document for Large Combustion Plants.
4. European Parliament and Council of European Union, November 2021, Commission Implementing Decision EU 2021/2326 Establishing Best Available Techniques (BAT) Conclusions Under Directive 2010/75/EU for Large Combustion Plants.
5. European Parliament and Council of European Union, 2015, Best Available Techniques (BAT) Reference Document for the Refining of Mineral Oil and Gas.
6. European Parliament and Council of European Union, October 2014, Commission Implementing Decision EU 2014/7155 Establishing Best Available Techniques (BAT) Conclusions Under Directive 2010/75/EU for the Refining of Mineral Oil and Gas.
7. European Parliament and Council of European Union, 2017. Best Available Techniques (BAT) Reference Document for Common Wastewater and Waste Gas Treatment/Management Systems in the Chemical Sector.
8. European Parliament and Council of European Union, May 2016, Commission Implementing Decision EU 2016/902 Establishing Best Available Techniques (BAT) Conclusions Under Directive 2010/75/EU for Common Wastewater and Waste Gas Treatment/Management Systems.
9. European Parliament and Council of European Union, 2023, Best Available Techniques (BAT) Reference Document for Common Waste Gas Management and Treatment Systems in the Chemical Sector.
10. European Parliament and Council of European Union, December 2022, Commission Implementing Decision EU 2022/2427 Establishing Best Available Techniques (BAT) Conclusions Under Directive 2010/75/EU for Common Waste Gas Management and Treatment Systems in the Chemical Sector.
11. European Parliament and Council of European Union, 2005 Best Available Techniques (BAT) Reference Document for Emissions from Storage.