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

Document Reference: Appendix C4 Assessment of Best Available Techniques For Energy Efficiency

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
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
MP	Medium Pressure
NEP	Northern Endurance Partnership
NWL	Northumbrian Water Limited
NZT	Net Zero Teesside
O_2	Oxygen
PSA	Pressure Swing Adsorption
WwTW	Wastewater Treatment Works

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TABLES

1.0 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 environmental permit for the proposed Carbon Capture and Storage (CCS) enabled Hydrogen (H2) Production Facility in the Teesside industrial cluster area in Redcar, Stockton-on-Tees.

1.1.2 The purpose of this report is to demonstrate the proposed Installation will be designed and operated in accordance with indicative best available techniques (BAT) for Energy Efficiency.

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 an up to 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 proposed 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 hydrogen production plant 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) for the proposed Installation is 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 with CC, Large Combustion Plant, Energy Efficiency, Capture plant design 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 this Energy Efficiency BAT Assessment.

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, including:

- EU Best Available Techniques (BAT) Reference Document for Energy Efficiency[(1)]; and
- Emerging Techniques for Hydrogen Production With Carbon Capture[(2)].

1.1.8 The main application document (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 hydrogen production with carbon capture, large combustion plant, cooling and emissions management please refer to the separate assessments:

- BAT Assessment for Hydrogen Production and Carbon Capture (Appendix C1; Document Reference: AP3328SQ/APP/BAT1-H2).
- 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 Emissions Management (Appendix C5; Document Reference: AP3328SQ-APP-BAT5-Emissions).

2.0 APPROACH TO BAT APPRAISAL

2.1.1 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.

2.1.2 At this stage of project development, while the technology provider for the hydrogen production with CCS 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 their process and solvent blend 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.

2.1.3 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.

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

3.0 ENERGY EFFICIENCY DEMONSTRATION FOR THE INSTALLATION

3.1 Design Basis for Energy Efficiency

3.1.1 The overall performance of the hydrogen production and carbon capture plant for optimised energy efficiency is dependent on, as far as practical, optimisation of electrical, steam, steam condensate and water circuits along with optimised integration of utilities.

3.1.2 Thermal modelling will be undertaken during each design phase to identify the key plant areas for energy performance management including consideration of:

- Optimised design of saturator circuit, Isothermal Temperature Shift (ITS) convertor and boiler to provide the steam input for the most efficient operation of the plant;
- Optimised recovery or reuse of low heat streams, including the reuse of waste heat from condensate.

3.1.3 The pressure swing adsorption (PSA) unit design will be optimised to remove traces of impurities to purify the hydrogen to >98 vol % H_2. The tail gas will be sent to the auxiliary boiler along with a portion of the hydrogen product to act as a fuel.

3.1.4 The carbon capture unit will be optimised by the technology licensor for the specific solvent characteristics. Energy will be recovered from the CO_2 removal unit using a hydraulic turbine coupled to a generator.

3.1.5 As design progresses through FEED consideration of further energy efficiency optimisations where practicable such as:

- Insulation of relevant areas of the plant to reduce heat loss during shutdown; and
- Heat recovery from compression systems.

3.2 Steam System

3.2.1 The medium pressure (MP) steam, saturated at 44.0 bara, is raised in the auxiliary boiler and is used to heat oxygen (O_2) in the O_2 preheater. This is injected upstream of the autothermal reformer (ATR) for the burners and is consumed in the deaerator head.

3.2.2 The remaining MP steam is superheated at 450 degrees Celsius and is primarily sent for use in the GHR-ATR reforming section with a small amount sent for use in the CO_2 dryer.

3.2.3 Intermediate pressure (IP) steam is raised in the ITS shift reactor and is also fed to the GHR-ATR reforming section.

3.2.4 Low pressure (LP) steam is used by the CO_2 stripper reboiler and deaerator.

3.3 Cooling System

3.3.1 The cooling systems will be designed to optimise energy efficiency. The major users of cooling water are the ATR unit, GHR unit and the CCP.

3.3.2 The plant will be cooled by cooling water towers, with raw water feed from Northumbrian Water Limited (NWL) as described in the BAT assessment for cooling water (AP3328SQ/APP/BAT3-COOL). The selection of the primary cooling systems is considered to represent BAT for the Installation.

3.3.3 The cooling system designs will be refined during FEED and optimised during commissioning to maximise energy efficiency of the Installation as a whole. Water Treatment

3.3.4 Demineralised water will be required for the dilution of make-up solvent within the Capture plant and boiler feed water, in addition to raw water make-up for cooling water requirements, as described in the Cooling BAT Assessment.

3.3.5 The anticipated raw water source is from either the existing NWL raw water supply to the Teesworks site or a new connection to the existing NWL supply either via a tie in to NZT infrastructure, or the Installation of a new connection.

3.3.6 Raw water will be pre-treated prior to demineralisation in a raw water treatment plant which may include coagulation, flocculation, clarification, dissolved air flotation (DAF), granular activated carbon ultrafiltration (UF) for removal of fine solids ultrafiltration (UF) for removal of fine solids and disinfection. In order to complete demineralisation process, water will pass through a double reverse osmosis (RO) for the removal of ions or other suitable technologies followed by electro-deionisation (EDI). The exact treatment package will be confirmed during FEED.

3.3.7 The opportunities for re-use and recovery of water within the process will be determined at FEED stage, but are anticipated to include:

- Steam system condensate;
- Recovery of cooling water blowdown through the effluent treatment plant; and
- Recovery of process condensate and flare knockout liquid through a bio-treatment plant.

3.3.8 Treatment of raw water to remove contaminants, such as suspended solids, avoids the build-up of solids in the pipework and thereby makes cooling more efficient.

3.4 Maintenance Philosophy

3.4.1 The operator will minimise the number of planned shutdowns as far as is practicable by harmonising and scheduling the maintenance of major equipment within the Installation, and by implementing an appropriate design, maintenance philosophy and spares strategy.

3.4.2 Maintenance routines will follow a cycle as shutdowns are required after a set number of operating hours or start-ups (whichever comes earliest).

3.4.3 All equipment for use in the proposed plant will be selected to maximise energy efficiency in the proposed duties, whilst considering the reliability, part load efficiency and other operating parameters.

3.4.4 Elements of the plant's design that help achieve the high energy efficiency include the following.

- Modern design following current best practices in optimising efficiency;
- The use of wet cooling instead of air cooling or direct once through cooling;
- High efficiency motors and drives to reduce parasitic loads;
- The use of plant components sized appropriately for the design capacity of the plant, so that each element is operating optimally and efficiently;
- Where needed variable speed drives (VSDs) will be included on all sizeable motors (such as boiler feed pumps and cooling water pumps) to optimise process control;
- The effective insulation of hot surfaces; and
- The plant is designed to be ready to export heat, to enable the potential for future use of heat from the plant and thus increase efficiency further.

3.4.5 The plant will also be subject to regular planned maintenance in order to optimise the efficiency of the equipment on site, including (but not limited to):

- Continuous and intermittent water quality maintenance activities, such as blowdown of the steam drum and injection of chemicals, to maintain the cycle water quality and optimum working medium;
- Boiler chemical cleaning;
- Optimised lubrication schedules in accordance with OEM specifications;
- Performance monitoring for motors, pumps, blowers and compressors;
- Production plant minor inspection regime; and
- Production major plant inspection/overhaul.

4.0 ENERGY EFFICIENCY BAT CONCLUSIONS FOR THE INSTALLATION

Table 4-1. BAT Conclusions For Energy Efficiency at an Installation Level

BAT Reference	BAT Description	H2 Teesside	
BAT 1	***Energy Efficiency Management*** BAT is to implement and adhere to an energy efficiency management system (ENEMS) that incorporates, as appropriate to the local circumstances, all of the following features (see Section 2.1. The letters (a), (b), etc. below, correspond those in Section 2.1):		
	a) commitment of top management (commitment of the top management is regarded as a precondition for the successful application of energy efficiency management) b) definition of an energy efficiency policy for the installation by top management c) planning and establishing objectives and targets (see BAT 2, 3 and 8) d) implementation and operation of procedures paying particular attention to: i. structure and responsibility ii. training, awareness and competence (see BAT 13) iii. communication iv. employee involvement v. documentation vi. effective control of processes (see BAT 14) vii. maintenance (see BAT 15) viii. emergency preparedness and response ix. safeguarding compliance with energy efficiency-related legislation and agreements (where such agreements exist).	As identified in the Supporting Statement (Section 4) the Operator will operate the Installation in accordance with an Environmental Management System (EMS). It is anticipated that the management of energy efficiency of the Installation will form part of this environmental management system. Further details of the management system will be developed prior to commencement of operations but will incorporate: • Relevant policy statements and other management documents. The EMS will recognise energy use as a significant aspect and energy efficiency as a key attribute to monitor and improve. The commitment to review and improve environmental impacts and associated performance will be captured within the EMS and it associated policy statements. • The EMS will include the annual establishment of objectives and targets including those associated with energy. Performance will be monitored in accordance with defined Key Performance Indicators (KPIs) which will be set once the plant is commissioned and is fully operational.	Yes

BAT Reference	BAT Description	H2 Teesside	
	e) benchmarking: the identification and assessment of energy efficiency indicators over time (see BAT 8), and the systematic and regular comparisons with sector, national or regional benchmarks for energy efficiency, where verified data are available (see Sections 2.1(e), 2.16 and BAT 9) f) checking performance and taking corrective action paying particular attention to: i. monitoring and measurement (see BAT 16) ii. corrective and preventive action iii. maintenance of records iv. independent (where practicable) internal auditing in order to determine whether or not the energy efficiency management system conforms to planned arrangements and has been properly implemented and maintained (see BAT 4 and 5) g) review of the ENEMS and its continuing suitability, adequacy and effectiveness by top management h) preparation and publication (and possibly external validation) of a regular energy efficiency statement describing all the significant environmental aspects of the installation, allowing for year-by-year comparison against environmental objectives and targets as well as with sector benchmarks as appropriate i) having the management system and audit procedure examined and validated by an accredited certification body or an external ENEMS verifier j) when designing a new unit, taking into account the environmental impact from the eventual decommissioning of the unit k) development of energy efficient technologies, and to follow developments in energy efficiency techniques	• Site-specific procedures which define roles and responsibilities for site personnel. **Monitoring and Measurement** • Monitoring and reporting of performance in relation to energy and energy efficiency requirements will be undertaken in accordance with the relevant section of any issued environmental permit. • Maintenance Plan: All plant and equipment at the Installation will be regularly maintained by qualified maintenance staff and contractors. **Corrective and Preventative Actions** • The Installation will be controlled and operated via a Distributed Control System (DCS) to continuously monitor the operation of the plant and equipment at the site. 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. **Records** • The EMS will clearly define the requirements for maintaining and storing records. **Auditing and Management Review** • The EMS will be subject to attestation with ISO 14001 and will be subject to periodic review and update and will be subject to internal audits.	
BAT 2	***Planning and Establishing Objectives and Targets*** BAT is to continuously minimise the environmental impact of an installation by planning actions and investments on an integrated	The proposed Installation has been designed to current compliance and design standards. It will be operated in accordance with the EMS, with regular appraisal of the	Yes

BAT Reference	BAT Description	H2 Teesside	
	basis and for the short, medium and long term, considering the cost-benefits and cross-media effects.	plant and equipment in use at the Installation. The EMS sets periodic objectives and targets to control and minimise the impact of operations, including energy consumption (considering the cost benefits).	
BAT 3	***Identification of Energy Efficiency Aspects of an Installation and Opportunities for Energy Savings*** BAT is to identify the aspects of an installation that influence energy efficiency by carrying out an audit. It is important that an audit is coherent with a systems approach (see BAT 7).	The Installation will be designed to current compliance and design standards. It will be operated in accordance with an EMS, with regular appraisal of the plant and equipment in use at the Installation.	Yes
BAT 4	***Identification of Energy Efficiency Aspects of an Installation and Opportunities for Energy Savings*** When carrying out an audit, BAT is to ensure that the audit identifies the following aspects (see Section 2.11): a) energy use and type in the installation and its component systems and processes b) energy-using equipment, and the type and quantity of energy used in the installation c) possibilities to minimise energy use, d) possibilities to use alternative sources or use of energy that is more efficient, in particular energy surplus from other processes and/or systems, see Section 3.3 e) possibilities to apply energy surplus to other processes and/or systems, see Section 3.3 f) possibilities to upgrade heat quality (see Section 3.3.2)	The EMS will include procedures for regular energy efficiency auditing. The BAT requirements (a-f) will be considerations during the assessments where applicable.	Yes
BAT 5	***Identification of Energy Efficiency Aspects of an Installation and Opportunities for Energy Savings*** BAT is to use appropriate tools or methodologies to assist with identifying and quantifying energy optimisation, such as: • Energy models, databases and balances (see Section 2.15) ◦ • A technique such as pinch methodology (see Section 2.12) exergy or enthalpy analysis (see Section 2.13), or thermoeconomics (see Section 2.14) • Estimates and calculations (see Sections 1.5 and 2.10.2)	Appropriate industry standard energy model tools, to identify energy efficiency optimisation measures will be used during plant design phases.	Yes

BAT Reference	BAT Description	H2 Teesside	
BAT 6	***Identification of Energy Efficiency Aspects of an Installation and Opportunities for Energy Savings*** BAT is to identify opportunities to optimise energy recovery within the installation, between systems within the installation (see BAT 7) and/or with a third party (or parties), such as those described in Sections 3.2, 3.3 and 3.4.	See Section 3.1 of this document. Process heat is used to drive reforming reaction in a Gas Heated Reformer (GHR)	Yes
BAT 7	***A Systems Approach to Energy Management*** BAT is to optimise energy efficiency by taking a systems approach to energy management in the installation. Systems to be considered for optimising as a whole are, for example: - Process unites - Heating systems – steam, hot water - Cooling and vacuum - Motor driven systems – compressed air, pumping - Lighting - Drying, separation and concentration	Appropriate industry standard energy model tools, to identify energy efficiency optimisation measures will be used during plant design phases – see Section 3 for further detail.	Yes
BAT 8	***Establishing and Reviewing Energy Efficiency Objectives and Indicators*** BAT is to establish energy efficiency indicators by carrying out all of the following: a) Identifying suitable energy efficiency indicators for the installation, and where necessary, individual processes, systems and/or units, and measure their change over time or after the implementation of energy efficiency measures (see Sections 1.3 and 1.3.4) b) Identifying and recording appropriate boundaries associated with the indicators (see Sections 1.3.5 and 1.5.1) c) identifying and recording factors that can cause variation in the energy efficiency of the relevant process, systems and/or units (see Sections 1.3.6 and 1.5.2).	Energy efficiency indicators, boundaries and variables will be developed and maintained as part of the EMS. Initial indicators for Installation will be developed by the Plant Operational Team during plant commissioning to ensure compliance with this BAT conclusion.	Yes
BAT 9	***Benchmarking*** BAT is to carry out systematic and regular comparisons with sector, national or regional benchmarks, where validated data are available.	The plant performance guarantees will be developed through the FEED process and benchmarked against performance information published from other	Yes

BAT Reference	BAT Description	H2 Teesside	
		developing blue hydrogen with CCS projects as well as performance data from test and commercial facilities. At this stage there are no published benchmarks or BAT-Achievable Energy Efficiency Levels for CCS projects to compare against and the work associated with this Installation will form part of the evidence base being developed.	
BAT 10	***Energy Efficient Design (EED)*** BAT is to optimise energy efficiency when planning a new installation, unit or system or a significant upgrade (see Section 2.3) by considering all of the following: a) The energy-efficient design (EED) should be initiated at the early stages of the conceptual design/basic design phase, even though the planned investments may not be well-defined. The EED should also be taken into account in the tendering process b) The development and/or selection of energy-efficient technologies (see Sections 2.1(k) and 2.3.1) c) Additional data collection may need to be carried out as part of the design project or separately to supplement existing data or fill gaps in knowledge d) The EED work should be carried out by an energy expert. e) The initial mapping of energy consumption should also address which parties in the project organisations influence the future energy consumption and should optimise the energy efficiency design of the future plant with them. For example, the staff in the (existing) installation who may be responsible for specifying design parameters.	Energy efficiency will be embedded at all stages of design – see section 3 for further detail.	Yes
BAT 11	***Increased Process Integration*** BAT is to seek to optimise the use of energy between more than one process or system (see Section 2.4), within the installation or with a third party.	See Section 3.1 of this document.	Yes

BAT Reference	BAT Description	H2 Teesside	
BAT 12	***Maintaining Impetus of Energy Efficiency Initiatives*** BAT is to maintain the impetus of the energy efficiency programme by using a variety of techniques, such as: a) Implementing a specific energy efficiency management system (see Section 2.1 and BAT1) b) Accounting for energy usage based on real (metered) values, which places both the obligation and credit for energy efficiency on the user/bill payer (see Sections 2.5, 2.10.3 and 2.15.2) c) The creation of financial profit centres for energy efficiency (see Section 2.5) d) Benchmarking (see Section 2.16 and BAT 9) e) A fresh look at existing management systems, such as using operational excellence (see Section 2.5) f) Using change management techniques (also a feature of operational excellence, see Section 2.5)	See response to BAT 1 -The efficient use of energy is embedded in the management system and performance requirements of the proposed Installation. The Installation will be subject to regular preventative maintenance cycles to ensure the efficiency of plant and equipment is maintained.	Yes
BAT 13	***Maintaining Expertise*** BAT is to maintain expertise in energy efficiency and energy-using systems by using techniques such as: a) Recruitment of skilled staff and/or training of staff. Training can be delivered by in-house staff, by external experts, by formal courses or by self-study/development (see Section 2.6) b) Taking staff off-line periodically to perform fixed term/specific investigations (in their original installation or in others, see Section 2.5). c) Sharing in-house resources between sites (see Section 2.5) d) Use of appropriately skilled consultants for fixed term investigations (e.g. see Section 2.11) e) Outsourcing specialist systems and/or functions (e.g. see Annex 7.12	The Installation will be operated by suitable personnel with required skills and training. The maintenance activities associated with the Installation will be undertaken by appropriately licensed contractors.	Yes
BAT 14	***Effective Control of Processes*** BAT is to ensure that the effective control of processes is implemented by techniques such as:	The operation of the Installation will be automated, with a Distributed Control System (DCS) providing continuous monitoring and control. The design philosophy of the DCS is to provide the maximum	Yes

BAT Reference	BAT Description	H2 Teesside	
	a) Having systems in place to ensure that procedures are known, understood and complied with (see Sections 2.1(d)(vi) and 2.5) b) Ensuring that the key performance parameters are identified, optimised for energy efficiency and monitored (see Sections 2.8 and 2.10). c) Documenting or recording these parameters (see Sections 2.1(d)(vi), 2.5, 2.10 and 2.15).	possible level of automation for all systems installed and the plant will, in general, operate automatically under operator supervision during normal operation. Semi-automatic sequences and manually requested actions will also be available via the DCS when required The monitoring and control of the Installation will be in accordance with the systems and procedures documented within the IMS.	
BAT 15	***Maintenance*** BAT is to carry out maintenance at installations to optimise energy efficiency by applying all of the following: a) Clearly allocating responsibility for the planning and execution of maintenance b) Establishing a structured programme for maintenance based on technical descriptions of the equipment, norms, etc. as well as any equipment failures and consequences. Some maintenance activities may be best scheduled for plant shutdown periods c) Supporting the maintenance programme by appropriate record keeping systems and diagnostic testing d) Identifying from routine maintenance, breakdowns and/or abnormalities possible losses in energy efficiency, or where energy efficiency could be improved e) Identifying leaks, broken equipment, worn bearings, etc. that affect or control energy usage, and rectifying them at the earliest opportunity.	The Installation will be subject to regular preventative maintenance cycles to ensure the efficiency of plant and equipment is maintained. A repair and maintenance management plan will be in place. Environmentally critical equipment will be identified and tagged for maintenance and to minimise emissions and discharges.	Yes
BAT 16	***Monitoring and Measurement*** BAT is to establish and maintain documented procedures to monitor and measure, on a regular basis, the key characteristics of operations and activities that can have a significant impact on energy efficiency. Some suitable techniques are given in Section 2.10.	The operations at the Installation will be monitored continuously to ensure optimum performance, including meeting energy efficiency objectives.	Yes

BAT Reference	BAT Description	H2 Teesside	
BAT 17	***Combustion*** BAT is to optimise the energy efficiency of combustion by relevant techniques such as those specific to sectors given in vertical BREFs.	See the responses in Table 2 below for Large Combustion Plant (LCP)	Yes
BAT 18	***Steam Systems*** BAT for steam systems is to optimise the energy efficiency by using techniques such as those specific to sectors given in vertical BREFs.	See the responses in Table 2 below for Large Combustion Plant (LCP)	Yes
BAT 19	***Heat Recovery*** BAT is to maintain the efficiency of heat exchangers by both: a) Monitoring the efficiency periodically b) Preventing or removing fouling	The design of heat exchange systems will be optimised during FEED and EPC design phases. This will include identifying the mechanisms to prevent or remove fouling. Monitoring of heat exchange efficiency will be a factor of the planned preventative maintenance regime and process monitoring via the DCS control system.	Yes
BAT 20	***Cogeneration*** BAT is to seek possibilities for cogeneration, inside and/or outside the installation (with a third party).	**Internal** • Process heat will be used to drive the reforming reaction in a Gas Heated Reformer (GHR). • Heat of syngas is also used to pre-heat the natural gas feed. • Steam recovery has been integrated and optimised for use on the wider plant with approximately 80% raised and recovered through the process and the remaining 20% provided from the auxiliary boilers. • Energy will be recovered from the CO_2 removal unit using a hydraulic turbine coupled to a generator. **External** The plant potential to supply heat to other external users will be further assessed during FEED. However, it should	Yes

BAT Reference	BAT Description		H2 Teesside	
			be noted that currently no viable offtake users are available in the area; and an appraisal of heat export opportunities will need to be undertaken as the wider area is developed	
BAT 21	***Electrical Power Supply*** BAT is to increase the power factor according to the requirements of the local electricity distributor by using techniques such as those in Table 4.3, according to applicability (see Section 3.5.1):			
	Technique	***Applicability***		
	Installing capacitors in the AC circuits to decrease the magnitude of reactive power	All cases. Low cost and long lasting, but requires skilled application	During early FEED it was confirmed that power factor compensation equipment would likely be required using multi-step capacitor banks to improve grid power factor to 0.9. This will be developed and optimised further during FEED.	Yes
	Minimising the operation of idling or lightly loaded motors	All cases	Design will be progressed during FEED so that motor design ensures that idling or lighted loaded motors are minimised.	Yes
	Avoiding the operation of equipment above its rated voltage	All cases	Design will be progressed and optimised during FEED to ensure selected equipment can be operated within its rated voltage. Design will ensure alignment between utilization and distribution voltage. Furthermore, the design includes a for tap changer on distribution transformers which would allow a level of control of the voltage at the distribution network.	Yes
	When replacing motors, using energy- efficient motors (see Section 3.6.1)	At time of replacement	N/A as this is a new plant	N/A
BAT 22	***Electrical Power Supply*** BAT is to check the power supply for harmonics and apply filters if required (see Section 3.5.2).		It was confirmed with vendors during early FEED that separate harmonic filters are unlikely to be required, however, this will be reviewed and finalised during FEED.	Yes

BAT Reference	BAT Description		H2 Teesside	
BAT 23	***Electrical Power Supply*** BAT is to optimise the power supply efficiency by using techniques such as those in Table 4.4, according to applicability: a) Ensure power cables have the correct dimensions for the power demand b) Keep online transformer(s) operating at a load above 40 – 50 % of the rated power c) Use high efficiency/low loss transformers d) Place equipment with a high current demand as close as possible to the power source (e.g. transformer)			
	Technique	***Applicability***		
	Ensure power cables have the correct dimensions for the power demand	When the equipment is not in use, e.g. at shutdown or when locating or relocating equipment	Cable schedule will be finalised and optimised during FEED and will ensure that correct cable sizing has been adopted.	Yes
	Keep online transformer(s) operating at a load above 40 - 50 % of the rated power	• for existing plants: when the present load factor is below 40 %, and there is more than one transformer • on replacement, use a low loss transformer and with a loading of 40 - 75 %	Load List as an Early FEED deliverable, confirms that adequate contingencies & growth factors been kept while sizing the transformers. Design is based on 2x100% rated transformers. During normal operation, both transformers will have loading of approximately 50%.	Yes
	Use high efficiency/low loss transformers	At time of replacement, or where there is a lifetime cost benefit	Transformer design will be finalised and optimised during FEED and will consider high efficiency transformers. The IOGP/JIP 33 requirement for Level 2 energy performance level as per IEC TS 60076-20 will be adopted, which is classified as high energy performance.	Yes
	Place equipment with a high current demand as close as possible to the power source (e.g. transformer)	When locating or relocating equipment	Cable routing layout as an Early FEED deliverable, shall ensure that all the electrical consumers to be fed from respective substations in a way which avoids any large voltage drops at motor terminals .	Yes
BAT 24	***Electric-motor-driven subsystems*** BAT is to optimise electric motors in the following order (see Section 3.6): 1. Optimise the entire system the motor(s) is part of (e.g. cooling system, see Section 1.5.1) 2. Then optimise the motor(s) in the system according to the newly determined load requirements, by applying one or more of the techniques in Table 4.5, according to applicability.			

BAT Reference	BAT Description		H2 Teesside	
	Technique	***Applicability***		
	SYSTEM INSTALLATION or REFURBISHMENT			
	Using energy-efficient motors (EEM)	Lifetime cost benefit	Use and design of electric motors will be determined during FEED and will be optimised to the system the motors will serve. This will include: • Ensuring motor sizing is sufficient and appropriate for duty; • VSD will be used where appropriate. • Optimising motor transmission system to minimise potential losses (e.g. selecting the most efficient belts, gears and coupling systems). • IE3 (premium efficiency) motors will be used where appropriate.	Yes
	Proper motor sizing	Lifetime cost benefit		
	Installing variable speed drives (VSD)	Use of VSDs may be limited by security and safety requirements. According to load. Note in multi-machine systems with variable load systems (e.g. CAS) it may be optimal to use only one VSD motor		
	Installing high-efficiency transmission/ reducers	Lifetime cost benefit		
	Use: • direct coupling where possible • synchronous belts or cogged V-belts in place of V belts • helical gears in place of worm gears	All		
	Energy-efficient motor repair (EEMR) or replacement with an EEM	At time of repair	N/A New Installation	N/A
	Rewinding: avoid rewinding and replace with an EEM, or use a certified rewinding contractor (EEMR)	At time of repair	N/A New Installation	N/A
	Power quality control	Lifetime cost benefit	A power factor correction device has been incorporated in the design to allow compliance with power factor requirements from the network owner so the need for this	Yes

BAT Reference	BAT Description		H2 Teesside	
			is unlikely, but it will be reviewed and confirmed during FEED.	
	SYSTEM OPERATION and MAINTENANCE			
	Lubrication, adjustments, tuning	All cases	The site will implement a planned preventative maintenance, and this will include defect monitoring, reporting and investigation as appropriate.	Yes
BAT 25	***Compressed Air*** BAT is to optimise compressed air systems (CAS) using the techniques such as those in Table 4.6, according to applicability:			
	Technique	***Applicability***		
	SYSTEM DESIGN, INSTALLATION or REPLACEMENT		Selection and optimisation of the air compressor configuration and control will be completed during FEED including consideration of: • optimising the overall system design and integration with the plant control system; • using IE3 (premium efficiency) motors where appropriate. • using VSDs where appropriate; and • recovering waste heat for use in other areas where practicable.	Yes
	Overall system design, including multi-pressure systems	New or significant upgrade		
	Upgrade compressor	New or significant upgrade		
	Improve cooling, drying and filtering	This does not include more frequent filter replacement (see below)		
	Reduce frictional pressure losses (for example by increasing pipe diameter)	New or significant upgrade		
	Improvement of drives (high-efficiency motors)	Most cost effective in small (<10 kW) systems		
	Improvement of drives (speed control)	Applicable to variable load systems. In multi-machine installations, only one machine should be fitted with a variable speed drive		
	Use of sophisticated control systems			
	Recover waste heat for use in other functions	Note that the gain is in terms of energy, not of electricity		

BAT Reference	BAT Description		H2 Teesside	
		consumption, since electricity is converted to useful heat		
	Use external cool air as intake	Where access exists		
	Storage of compressed air near highly fluctuating uses	All cases		
	SYSTEM OPERATION and MAINTENANCE			
	Optimise certain end use devices	All cases	The site will implement a planned preventative maintenance, and this will include plant optimisation, defect monitoring, reporting and investigation as appropriate.	Yes
	Reduce air leaks	All cases – largest potential gain		
	More frequent filter replacement	Review in all cases		
	Optimise working pressure	All cases		
BAT 26	***Pumping Systems*** BAT is to optimise pumping systems by using the techniques in Table 4.7, according to applicability (see Section 3.8)			
	Technique	***Applicability***		
	DESIGN			
	Avoid oversizing when selecting pumps and replace oversized pumps	For new pumps: all cases For existing pumps: lifetime cost benefit	Pump selection will be optimised during FEED to ensure correct pump selection in terms of sizing, duty of motors and distribution system	Yes
	Match the correct choice of pump to the correct motor for the duty	For new pumps: all cases For existing pumps: lifetime cost benefit		
	Design of pipework system (see Distribution system, below)			
	CONTROL and MAINTENANCE			
	Control and regulation system	All cases	Pump selection and associated control systems will be optimised during FEED including: • integration of the control systems; • use of VSDs where appropriate; and	Yes
	Shut down unnecessary pumps	All cases		
	Use of variable speed drives (VSDs)	Lifetime cost benefit. Not applicable where flows are constant		

BAT Reference	BAT Description		H2 Teesside	
	Use of multiple pumps (staged cut in)	When the pumping flow is less than half the maximum single capacity	• optimising planned preventative maintenance requirement .	
	Regular maintenance. Where unplanned maintenance becomes excessive, check for: • cavitation • wear • wrong type of pump	All cases. Repair or replace as necessary	The site will implement a planned preventative maintenance, and this will include defect monitoring, reporting and investigation as appropriate.	Yes
	DISTRIBUTION SYSTEM			
	Minimise the number of valves and bends commensurate with keeping ease of operation and maintenance	All cases at design and installation (including changes). May need qualified technical advice	Pipework routing and design will be optimised during FEED to ensure appropriate diameters are appropriate for their duty and to minimise the number of valves and bends .	Yes
	Avoiding using too many bends (especially tight bends)			
	Ensuring the pipework diameter is not too small (correct pipework diameter)			
BAT 27	**Heating, Ventilation and Air Conditioning (HVAC) Systems** BAT is to optimise heating, ventilation and air conditioning systems by using techniques such as: a) For ventilation, space heating and cooling, techniques in Table 4.8 according to applicability b) For heating, see Sections 3.2 and 3.3.1, and BAT 18 and 19 c) For pumping, see Section 3.8 and BAT 26 d) For cooling, chilling and heat exchangers, see the ICS BREF, as well as Section 3.3 and BAT 19			
	Technique	***Applicability***		
	DESIGN and CONTROL			
	Overall system design. Identify and equip areas separately for:	New or significant upgrade. Consider for retrofit on lifetime cost benefit	This will be progressed during the FEED stage and relevant aspects will be considered and optimised at	Yes

BAT Reference	BAT Description		H2 Teesside	
	• general ventilation • specific ventilation • process ventilation		this stage with consideration to relevant BAT requirements such as: • optimising and reducing heating and/or cooling needs across the Installation; • optimising the number, shape and size of intakes where these are need: • optimising the overall design of any air system employed; • integration of the automated control systems; and • utilising VSD motors where appropriate.	
	Optimise the number, shape and size of intakes	New or upgrade		
	Use fans: • of high efficiency • designed to operate at optimal rate	Cost effective in all cases		
	Manage airflow, including considering dual flow ventilation	New or significant upgrade		
	Air system design: • ducts are of a sufficient size • circular ducts • avoid long runs and obstacles such as bends, narrow sections	New or significant upgrade		
	Optimise electric motors, and consider installing a VSD	All cases. Cost effective retrofit		
	Use automatic control systems. Integrate with centralised technical management systems	All new and significant upgrades. Cost effective and easy upgrade in all cases		
	Integration of air filters into air duct system and heat recovery from exhaust air (heat exchangers)	New or significant upgrade. Consider for retrofit on lifetime cost benefit. The following issues need to be taken into account: the thermal efficiency, the pressure loss, and the need for regular cleaning.		

BAT Reference	BAT Description		H2 Teesside	
	Reduce heating/cooling needs by: • building insulation • efficient glazing • air infiltration reduction • automatic closure of doors • destratification • lowering of temperature set point • during non-production period (programmable regulation) • reduction of the set point for heating and raising it for cooling	Consider in all cases and implement according to cost benefit		
	Improve the efficiency of heating systems through: • recovery or use of wasted heat (Section 3.3.1) • heat pumps • radiative and local heating systems coupled with reduced temperature set points in the non-occupied areas of buildings	Consider in all cases and implement according to cost benefit	• Process heat will be used to drive the reforming reaction in a Gas Heated Reformer (GHR) and will also be used to pre-heat natural gas. • Steam recovery has been integrated and optimised for use on the wider plant with approximately 80% raised and recovered through the process and the remaining 20% provided from the auxiliary steam boilers.	Yes
	Improve the efficiency of cooling systems through the use of free cooling	Applicable in specific circumstances	Not applicable	N/A
	MAINTENANCE			
	Stop or reduce ventilation where possible	All cases	The site will implement planned preventative maintenance, and this will include plant optimisation,	Yes

BAT Reference	BAT Description		H2 Teesside	
	Ensure system is airtight, check joints		defect monitoring, reporting and investigation as appropriate.	
	Check system is balanced			
	Manage airflow: optimise			
	Air filtering, optimise: • recycling efficiency • pressure loss • regular filter cleaning/replacement • regular cleaning of system			
BAT 28	***Lighting*** BAT is to optimise artificial lighting systems by using the techniques such as those in Table 4.9 according to applicability (see Section 3.10):			
	Technique	***Applicability***		
	ANALYSIS and DESIGN OF LIGHTING REQUIREMENTS			
	Identify illumination requirements in terms of both intensity and spectral content required for the intended task	All cases	Illumination requirements will be optimised during FEED and will consider these three BAT aspects.	Yes
	Plan space and activities in order to optimise the use of natural light	Where this can be achieved by normal operational or maintenance rearrangements, consider in all cases. If structural changes, e.g. building work, is required, new or upgraded installations		
	Selection of fixtures and lamps according to specific requirements for the intended use	Cost benefit on lifetime basis		

BAT Reference	BAT Description		H2 Teesside	
	OPERATION, CONTROL, and MAINTENANCE			
	Use of lighting management control systems including occupancy sensors, timers, etc.	All cases	Lighting management control systems will be reviewed, and appropriate consideration given to occupancy sensors, timers and similar controls during FEED stage	Yes
	Train building occupants to utilise lighting equipment in the most efficient manner	All cases	Energy management/efficiency awareness training will be given to all personnel as part of the IMS.	Yes
BAT 29	**Drying, Separation and Concentration Processes** BAT is to optimise drying, separation and concentration processes by using techniques such as those in Table 4.10 according to applicability, and to seek opportunities to use mechanical separation in conjunction with thermal processes:			
	Technique	***Applicability***		
	DESIGN			
	Select the optimum separation technology or combination of techniques (below) to meet the specific process equipment.	All cases	Drying process will be used to remove moisture from the CO_2 product via solid bed desiccant process. Techno-commercial analysis has been performed to choose the most feasible dryer configuration for solid bed desiccant process.	Yes
	OPERATION			
	Use of surplus heat from other processes	Depends on the availability of surplus heat in the installation (or from third party)	Not applicable for the Installation.	N/A
	Use a combination of techniques	Consider in all cases	Not applicable.	N/A
	Mechanical processes, e.g. filtration, membrane filtration	Process dependent. To achieve high dryness at lowest energy consumption, consider these in combination with other techniques	Not applicable.	N/A

BAT Reference	BAT Description		H2 Teesside	
	Thermal processes, e.g. • directly heated dryers • indirectly heated dryers • multiple effect	Widely used, but efficiency can be improved by considering other options in this table	Not applicable.	N/A
	Direct drying	See thermal and radiant techniques, and superheated steam	Not applicable.	N/A
	Superheated steam	Any direct dryers can be retrofitted with superheated steam. High cost, needs lifetime cost benefit assessment. High temperature may damage product	Not applicable.	N/A
	Heat recovery (including MVR and heat pumps)	Consider for almost any continuous hot air convective dryers	Not applicable.	N/A
	Optimise insulation of the drying system	Consider for all systems. Can be retrofitted	Not applicable.	N/A
	Radiation processes e.g. • infrared (IR) • high frequency (HF) • microwave (MW)	Can be easily retrofitted. Direct application of energy to component to be dried. They are compact and Reduce the need for air extraction. IR limited by substrate dimensions. High cost, needs lifetime cost benefit assessment	Not applicable.	N/A
	CONTROL			
	Process automation in thermal drying processes	All cases	Solid desiccant drying process is highly automated (sequencing) and will require minimum operator intervention during normal operation.	Yes

5.0 ENERGY EFFICIENCY BAT CONCLUSIONS FOR LARGE COMBUSTION PLANT

Table 2. Energy Efficiency BAT Conclusions for Large Combustion Plant

BAT No	BAT Requirement		Demonstration of BAT – H2 Teesside Operator Response	
LCP 12	**BAT 12. In order to increase the energy efficiency of combustion, gasification and/or IGCC units operated ≥ 1,500h/yr, BAT is to use an appropriate combination of the techniques given below**			
	Technique	**Description**		
	Combustion optimisation	Optimising the combustion minimises the content of unburnt substances in the flue-gases and in solid combustion residues	The specific control settings for the combustion units shall be preset in the control system to achieve efficient combustion and optimise plant efficiency.	Yes
	Optimisation of the working medium conditions	Operate at the highest possible pressure and temperature of the working medium gas or steam, within the constraints associated with, for example, the control of NOx emissions or the characteristics of energy demanded	Performance tests of the Hydrogen Production Installation shall be undertaken during commissioning and then periodically in accordance with applicable BE EN standards.	Yes
	Optimisation of the steam cycle	Operate with lower turbine exhaust pressure by utilisation of the lowest possible temperature of the condenser cooling water, within the design conditions	Although the facility will include a steam system which provides heat into the process, it will not include provision of a turbine. The efficiency of the plant will be driven by the design of the hydrogen production plant including the steam system. The plant will be designed to exploit optimum steam pressure and temperature settings to maximise the overall efficiency.	Yes
	Minimisation of energy consumption	Minimising the internal energy consumption (e.g. greater efficiency of the feed-water pump)	All plant and equipment will be designed or specified and maintained to ensure optimal operation.	Yes
	Preheating of combustion air	Reuse of part of the heat recovered from the combustion flue-gas to preheat the air used in combustion	Combustion air will be pre-heated via a combustion air pre-heater coil utilising recovered heat, to optimise combustion.	Yes
	Fuel preheating	Preheating of fuel using recovered heat	A letdown heater has been provided to ensure the NG feed temperature does not fall below the acceptable operating range during pressure letdown from the supply line. The NG feed is then heated up in the feed gas preheater (fired heater	Yes

BAT No	BAT Requirement		Demonstration of BAT – H2 Teesside Operator Response	
	Advanced control system	See description in Section 10.8.2. Computerised control of the main combustion parameters enables the combustion efficiency to be improved	Operation of the hydrogen production units will be controlled by trained site operators using an automated control system, which will be used to control the operation of the plant. The control system will record the data on the plant performance which can be used by the operations team to identify potential issues. The specific control settings for the combustion units shall be pre-set in the control system to achieve efficient combustion and optimise plant efficiency.	Yes
	Feed-water preheating using recovered heat	Preheat water coming out of the steam condenser with recovered heat, before reusing it in the boiler	Once steam energy has been used, the remaining energy will be recovered by condenser and transferred to the feed-water system.	Yes
	Heat recovery by cogeneration (CHP)	Recovery of heat (mainly from the steam system) for producing hot water/steam to be used in industrial processes/activities or in a public network for district heating.	The plant has the potential to supply heat to other users which will be explored further during FEED; however an appraisal of heat export opportunities will be undertaken once the wider area is developed. However, the steam demand for the Hydrogen production plant would take precedence over off site users.	Yes
	CHP readiness	See description in Section 10.8.2.	Not applicable	N/A
	Flue-gas condenser	See description in Section 10.8.2.	Not applicable	N/A
	Heat accumulation	Heat accumulation storage in CHP mode	Not applicable	N/A
	Wet stack	Generally applicable to new and existing units fitted with wet FGD	Not applicable	N/A
	Cooling tower discharge	Only applicable to units fitted with wet FGD where reheating of the flue-gas is necessary before release, and where the unit cooling system is a cooling tower	Not applicable	N/A
	Fuel pre-drying	Only applicable to solid-fuel-fired combustion units and to gasification/IGCC units	Not applicable	N/A
	Minimisation of heat losses	Only applicable to new plants	The plant will be designed to exploit optimum steam pressure and temperature settings to maximise the overall efficiency and to minimise heat losses.	Yes

BAT No	BAT Requirement		Demonstration of BAT – H2 Teesside Operator Response	
	Advanced materials	Use of advanced materials proven to be capable of withstanding high operating temperatures and pressures and thus to achieve increased steam/combustion process efficiencies	The site will be a new low carbon hydrogen production plant and will be designed using suitable materials available at the time of construction to optimise operations.	Yes
	Steam turbine upgrades	This includes techniques such as increasing the temperature and pressure of medium-pressure steam, addition of a low-pressure turbine, and modifications to the geometry of the turbine rotor blades	Not applicable	N/A
	Supercritical and ultra-supercritical steam conditions	Use of a steam circuit, including steam reheating systems, in which steam can reach pressures above 220.6 bar and temperatures above 374 °C in the case of supercritical conditions, and above 250 – 300 bar and temperatures above 580 – 600 °C in the case of ultra-supercritical conditions	Not applicable	N/A

6.0 CONCLUSION

6.1.1 On the basis of the assessment against the required BAT Conclusions, as shown in Sections 4 and 5, and in the principles to be applied in the design and integration of the Hydrogen Production and Carbon Capture plant, it is considered that the proposed Installation will be designed and operated in compliance with the Energy Efficiency BRef and in accordance with BAT for energy efficiency.

7.0 REFERENCES

1. European Commission, September 2009, Reference Document on Best Available Techniques for Energy Efficiency.
2. Environment Agency, February 2023, Hydrogen Production With Carbon Capture: Emerging Techniques.