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Operating Techniques & BAT Assessment for BIOCCUS Project

BIOCCUS
The Grain Store,
Holmsted Farm,
Cuckfield,
West Sussex
RH17 5JF

Report for Environment Agency

Confidential

Customer:

Environment Agency

Customer reference:

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Ricardo is certified to ISO9001, ISO14001, ISO27001 and ISO45001

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Glossary

Abbreviation	Definition
BAT	Best Available Techniques
BATc	Best Available Techniques Conclusions
BEIS	Department for Business, Energy & Industrial Strategy
BIOCCUS	Biomass pyrolysis-based cogeneration system with biochar production and carbon capture, utilisation and storage
CC	Carbon Capture
CEMS	Continuous Emission Monitoring System
CHP	Combined Heat & Power
CIP	Clean in Place
CO	Carbon Monoxide
CO_2	Carbon Dioxide
DAA	Directly Associated Activities
DMA	Dimethylamine
EA	Environment Agency
EMS	Environmental Management System
EPR	The Environmental Permitting (England and Wales) Regulations 2016

Abbreviation	Definition
EWC	European Waste Code
FTIR	Fourier Transform Infrared
HCl	Hydrogen Chloride
HCN	Hydrogen Cyanide
HF	Hydrogen Fluoride
IED	Industrial Emissions Directive
MCP	Medium Combustion Plant
MDEA	Methyldiethanolamine
NDMA	N-Nitrosodimethylamine
NOx	Nitrogen Oxides
O2	Oxygen
PCC	Post-combustion carbon capture
PM	Particulate Matter
PZ	Piperazine
SAC	Special Area of Conservation
SG	Specified Generator
SHEQ	Safety, Health, Environmental and Quality
SO_2	Sulphur Dioxide
SWIP	Small Waste Incineration Plant
TVOC	Total Volatile Organic Compounds

1 Introduction

1.1 Overview

The BIOCCUS project has been selected for Phase 2 of the Direct Air Capture and Greenhouse Gas Removal competition, operated by the Department for Business, Energy & Industrial Strategy (BEIS).

The project will be a research & development (R&D) focused demonstration project, with the aim of developing a biomass pyrolysis-based cogeneration system with biochar production and carbon capture, utilisation and storage (BIOCCUS). Biochar will be produced from the pyrolysis process, while the carbon dioxide (CO_2) will be captured via a post-combustion amine-based carbon capture system.

This process consists of four key stages: i) pyrolysis of the waste biomass into biochar and syngas; ii) combustion of the syngas; iii) generation of power in the hot air turbine; iv) removal of CO_2 from the flue gas with carbon capture technology. A block flow diagram of the process is presented in Figure 1.

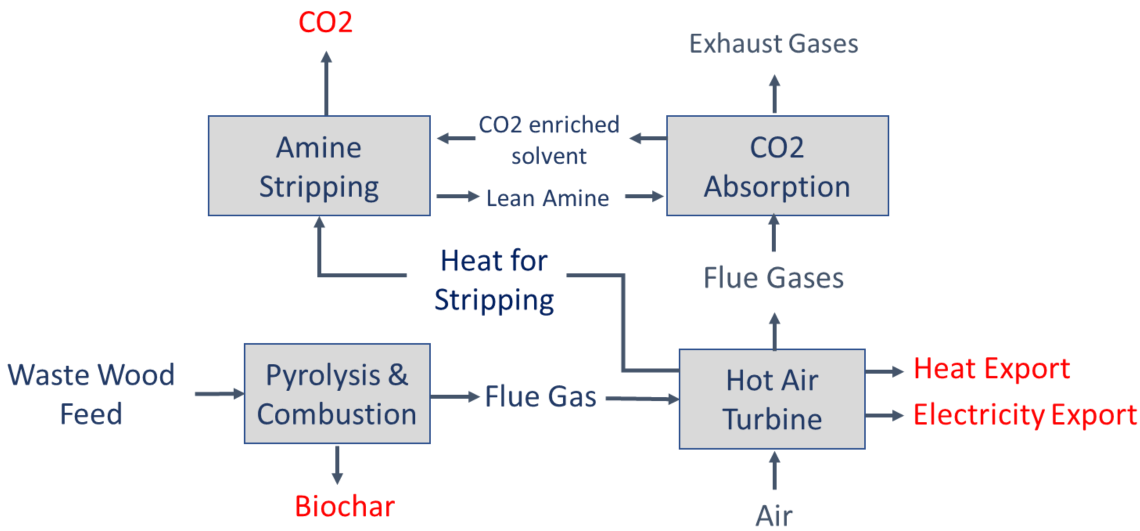

Figure 1: Block Flow Diagram of Process

The activities that will be undertaken are listed in Schedule 1 of the Environmental Permitting (England and Wales) Regulations 2016 (EPR) and therefore the operator must hold an environmental permit.

This document provides a technical description of the facility and its operations, details of the operating techniques that will be employed and how the facility complies with the associated Best Available Techniques (BAT).

1.2 Pre-application advice

Prior to applying for an environmental permit, Ricardo sought advice from the Environment Agency (EA) through the pre-application advice service, application reference number EPR/CP3620PC/A001. The advice received is included in Appendix A6.

The EA considers the listed activity to be regulated as a Part B activity: Section 5.1B(a)(v) which requires a supporting air emissions risk assessment and BAT assessment. The combustion activity also qualifies as a Medium Combustion Plant (MCP) and Specified Generator (SG). In a discussion with the EA on 14th March 2023, it was agreed that the carbon capture activity falls under the R&D exemption. The BAT assessment covers what is relevant for Section 5.1 Part B activities, i.e. the biomass pyrolysis activity, and includes a systematic review of the proposed operating techniques in accordance with EA guidance on BAT for post-combustion carbon capture. The BAT assessment only needs to cover the area of risk regulated by the permit, i.e., emissions to air. The pre-application advice received stated that noise and odour assessments are not required. Should the operator wish to continue operating the carbon capture activity once the R&D phase is finished, the operator will apply for a permit variation to include this activity. The R&D phase will be completed by March 2025.

We have also provided an indicative assessment in Appendix A3 to quantify potential impacts from the onsite carbon capture process based on the best available data for ELVs, bearing in mind that there is significant uncertainty around potential emissions as this is a novel process.

1.3 Site Location & Environmental Setting

The site is called Holmsted Farm, located on Staplefield Road in Cuckfield, West Sussex, as shown in

Figure 2[1]. A 669 m^2 unit with 7m eaves will be rented on this site for housing the process plant, as shown in Figure 3. Internal measurements are as follows: 24m width, 30m depth. A technical drawing of the unit is shown in Figure 4. The unit also has a connection to mains water and electricity. Two roller shutter loading doors provide the access requirements needed for installing the plant.

The site is located amongst other business units on Holmsted Farm and is surrounded by primarily agricultural land. The B2114 is located approximately 150m to the east of the site and Sloughgreen Lane is approximately 380m to the south of the site. There are various small ponds located in the surrounding area, the closest of which is approximately 85m to the east of the site. The closest residential dwelling is a house approximately 80m to the northeast of the site.

The geology of the site consists of Cuckfield Stone Bed and Lower Grinstead Clay bedrock, designated a moderately productive aquifer. There are no superficial deposits recorded.

A lease for hire of the building has been agreed in principle and will be signed following receipt of planning permission from the local authority. The planning application will be submitted shortly, a change of use application is being prepared for submission in the first week of September 2022.

[1] Home | Holmsted Farm: Bell tents, Business Units and Camping in Cuckfield

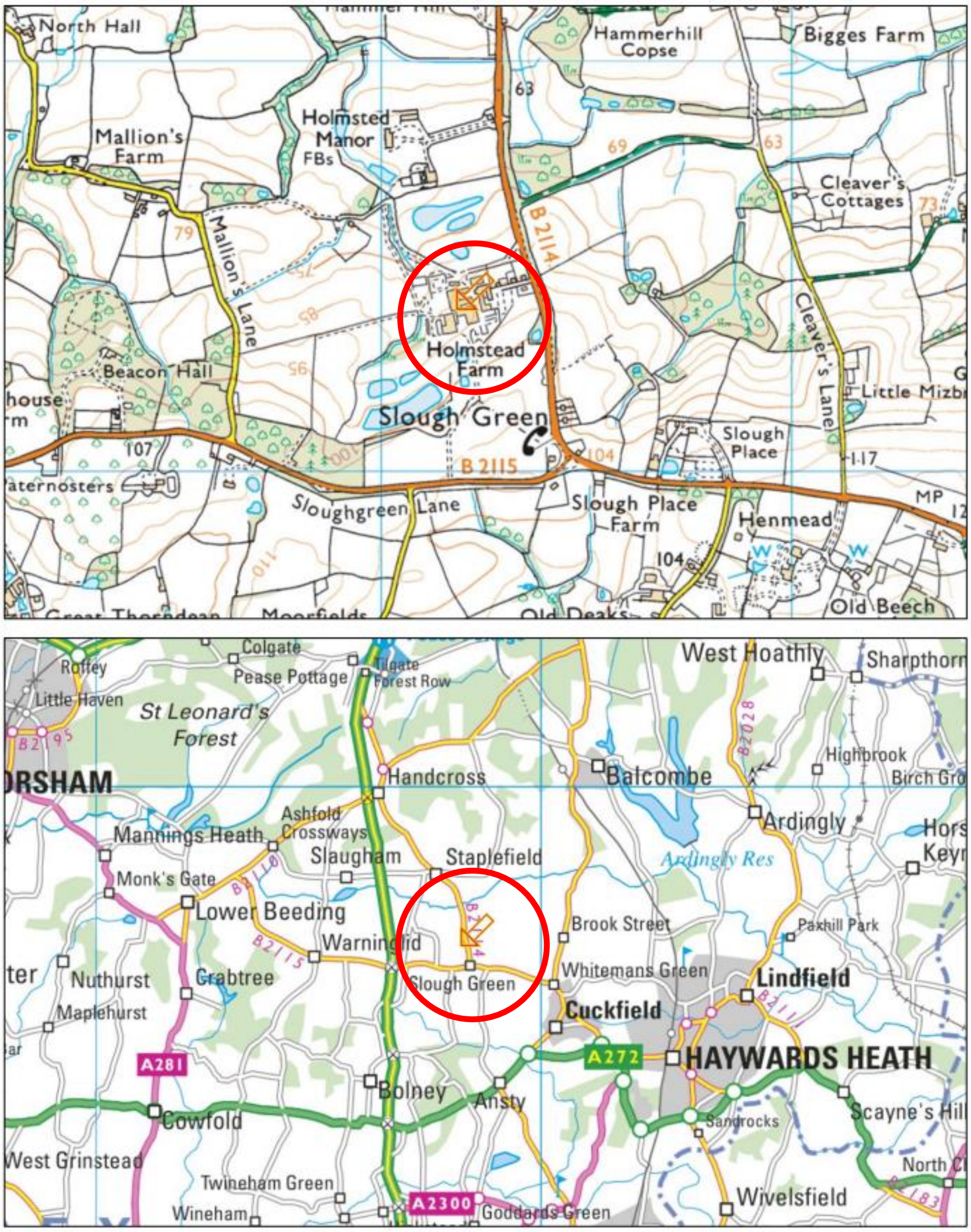

Figure 2: Location of Holmsted Farm

Figure 3: The unit to be rented at Holmsted Farm

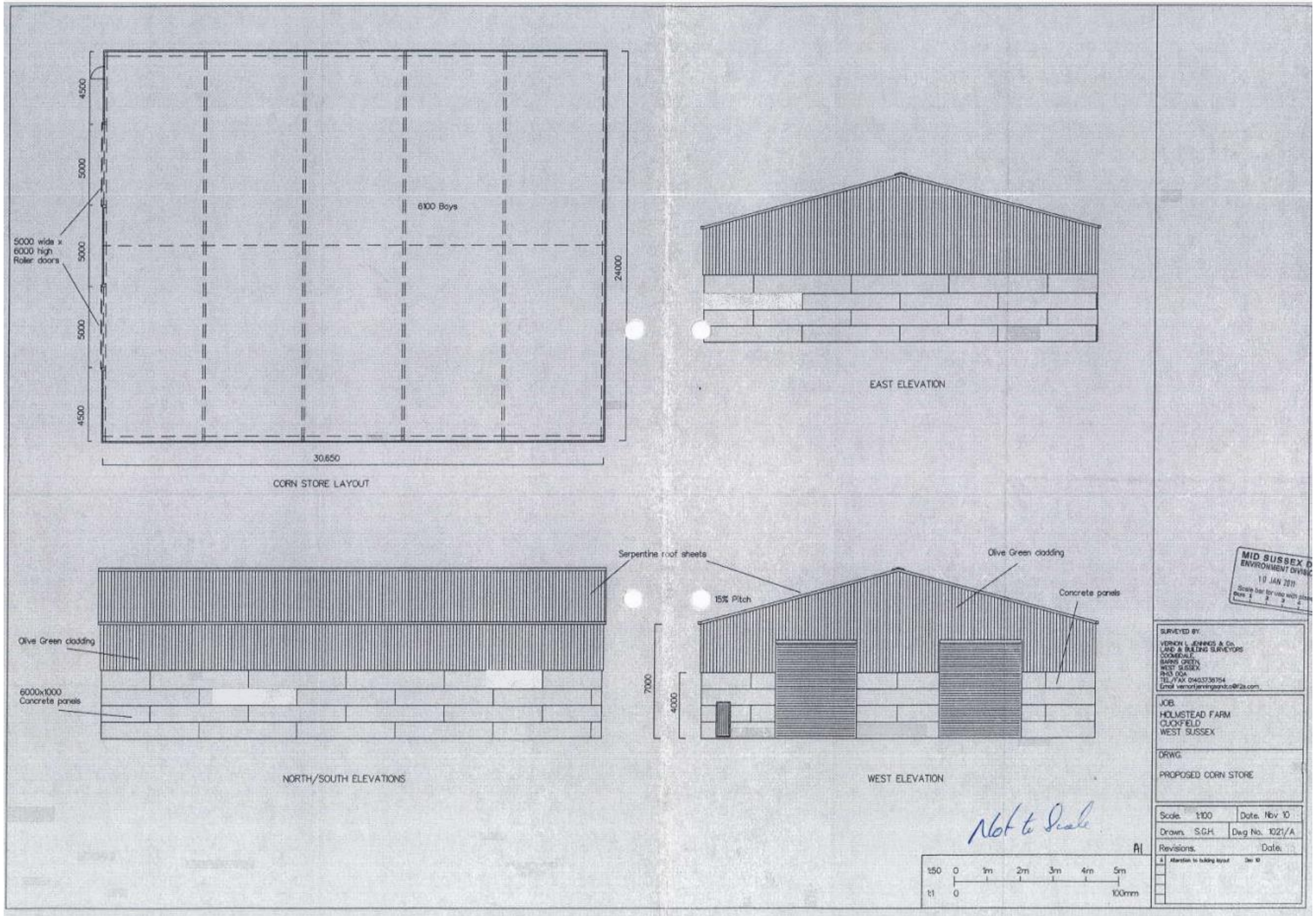

Figure 4: Technical Drawing of Unit

1.4 Summary of Process

The fuel for the process will be waste wood from domestic timber production, which is verified as sustainable and sourced locally to the BIOCCUS system. The pyrolysis unit will generate biochar and syngas from this waste wood. The biochar produced will be taken off-site for use as a soil improver or as an anaerobic digestion sorbent. Synthesis gas or 'syngas', is a mixture of hydrogen, carbon dioxide and carbon monoxide.

The syngas from the pyroliser will be combusted and the heat generated will be further utilised in the hot air turbine to generate heat and electricity. Some of the generated heat and electricity will be consumed by the carbon capture system and the biomass dryer. The remaining heat and electricity generated by the turbine will be exported to local domestic and commercial properties.

The flue gas produced from the pyroliser contains 11% CO_2. A proportion of this gas is passed into the R&D carbon capture unit where the CO_2 is removed using an amine-based absorption-stripping process. Methyldiethanolamine (MDEA) is the main amine selected for use within the system. Piperazine (PZ) will also be added to this solution to enhance the ability of the solvent to remove CO_2 from the flue. The carbon capture unit generates two streams, exhaust gas (with the majority of the CO_2 removed) and a CO_2 rich gas stream. Initially, for the purposes of proving out the technology, the CO_2 will be emitted to air with the other flue gases until a suitable end-user can be identified. If the operator chooses to continue with the carbon capture activity after the R&D phase, it is intended that the CO_2 will be converted to a permanent end product such as CO_2-cured concrete.

2 Listed Activities

The facility involves a Schedule 1 Section 5.1 Part B(a)(v) activity of the EPR (as amended). In England this activity is regulated by the EA. The Schedule 1 activity is detailed in Table 1 and includes incineration of wood waste at a rate of more than 50 kg per hour.

Table 1: Proposed EPR Schedule 1 Activities

Schedule 1 Activity	Description
Section 5.1B(a)(v)	(a) The incineration in a small waste incineration plant with an aggregate capacity of 50kg or more per hour of the following waste— (v) wood waste with the exception of wood waste which may contain halogenated organic compounds or heavy metals as a result of treatment with wood preservatives or coatings;

The waste wood intended for use as the feedstock falls within those European Waste Catalogue (EWC) codes that are exempt from the requirements of Chapter IV of the Industrial Emissions Directive, as set out in Section 3.1.1. The storage and drying of this waste wood prior to burning in the Part B co-incinerator is covered by regulatory position statement (RPS) 213. Virgin wood feedstock will also be trialled at the plant.

“Directly associated activities” (DAAs) are defined in paragraph 1 of Part 1 of Schedule 1 as an *operation which has a technical connection with a primary activity, is carried out at the same site as a primary activity and could have an impact on pollution*. The DAAs that are proposed for the facility are presented in Table 2.

Table 2: Proposed Directly Associated Activities

Directly Associated Activity	Description
Hot air turbine	Operation of a hot air turbine to generate electricity and heat for plant-use and export.
Carbon Capture (CC)	Operation of a CC system with an amine-based absorbent.
Handling of waste wood	Handling, drying and storage of waste wood feedstock.
Potentially Polluting substances	Storage of potentially polluting substances, to be treated offsite.
Utilities	Supply of utilities and services such as electricity, water, steam, and process cooling.
Biochar production and storage	Biochar is produced as a product from the pyrolysis of biomass.

As stated in Section 1, the carbon capture activity will fall under the R&D exemption. Should the operator wish to continue with the carbon capture activity after the R&D phase, a permit variation will be applied for.

3 Operating Techniques

3.1 Process Description

3.1.1 Feedstock acceptance criteria

The required classification code of the biomass will be stated in the purchase agreements with suppliers and the waste transfer documentation will be checked upon delivery. Due to the R&D nature of the project, more than one feedstock will be tested, including virgin wood. However, any waste wood used will fall within the list of acceptable waste codes listed in the Environmental Permitting Technical Note PG5/1(21) reference document for the incineration or combustion of waste wood:

Table 3: Acceptable waste codes under PG5/1(21)

EWC Code	Description	Further restriction
02 01 03 02 01 07	Plant tissue waste from agriculture, horticulture and forestry	-
03 01 01	Waste bark and cork from wood processing and the production of panels and furniture	No chemical treatment applied
03 01 05	Sawdust, shavings, cuttings, wood, particle board and veneer that is fixed to the board other than those mentioned in 03 01 04	No chemical treatment applied
03 03 01	Waste bark and wood from pulp, paper and cardboard production and processing	No chemical treatment applied
15 01 03	Wooden packaging	Visibly clean wooden packaging, including pallets, no chemical treatment applied
19 12 07	Wood other than wood containing hazardous substances (19 12 06) from waste management facilities	Source segregated visibly clean single waste wood stream such as pallets where no chemical treatments have been applied Post-segregation of mixed waste wood stream from civic amenity sites or skip hire operators is not sufficient

Any waste wood that has been classified as hazardous waste or has come from construction and demolition works (i.e. Grade B, C & D), will not be used as a feedstock for BIOCCUS.

The site team will carry out basic visual inspections on each delivery to the site to ensure the feedstock matches the EWC code and complies with any further restrictions (e.g., ensuring 15 01 03 is visibly clean wooden packaging). In the event that unacceptable waste is identified, the load will not be accepted and will be sent back to the supplier. In the unlikely event that the unacceptable waste is identified after it has been unloaded in the building, the load will be kept in the building, away from other wastes and ignition sources, until a suitably licensed waste handler collects it for disposal or treatment at another licensed site (less than 1 month).

3.1.2 Feedstock handling & drying

Untreated wood chips (Biomass) are dried using the residual heat from the flue gas scrubber cooler and Amine reflux condenser, before entering the pyrolysis process. The pyrolysis process can be fed at a rate of up to 350 kg/hr biomass, equating to 1.2 - 1.9 MWth, depending on the Lower Heating Value of the feedstock.

The feedstock dryer is an existing piece of equipment that is fitted with its own controller. It measures the moisture of the feedstock output and controls the fan speeds to regulate this to a desired setpoint. In addition, it controls the feedstock conveyors and monitors temperatures within the unit.

3.1.3 Raw materials supply, storage and handling

The estimates for consumption of raw materials and water are presented in Table 4 and are based on 8,000 hours of operation per year for the pyrolysis activity and 4,000 hours of operation per year for the CCUS activity. It should be noted that the initial phases of operation will be significantly lower than 8,000 or 4,000 hours per year while the technology is being demonstrated and evaluated.

Deliveries of liquids will be via a sealed connection. Spillage kits will be located in close proximity to the areas where raw materials will be delivered, stored and used. All site staff will be trained in the appropriate measures to be carried out in the event of a spill.

The biomass feedstock will be delivered via road and will be unloaded onto the floor of the building prior into a central pile as set out in Section 3.1.4, The building has fast acting roller shutter doors to allow access. No more than 125 tonnes of waste wood will be stored on site at any one time and it will be kept in piles less than 4m high. Only clean, untreated (grade A) waste wood will be stored prior to use in the BIOCCUS process. Waste wood will be stored for a maximum of one month at a time, but in most cases the storage time will be much lower. No other waste activity or treatment of the waste wood (shredding, chipping or pre-treating) will be carried out on site.

Lime (ground limestone) will be used in the flue gas treatment process, for the removal of acid gases in the flue gas for certain feedstocks. Up to 20 tonnes will be stored in bags in the building on the site at any one time, equating to up to 40 tonnes per annum.

The solvent used will be 40% amine, 60% water. Due to the R&D nature of the project, the amount of the promotor, PZ, to MDEA will be varied, but the split will nominally be 80% MDEA, 20% PZ of the 40% amine. Approximately 10 tonnes of amine will be required per annum for full operation. The amines will be stored in sealed containers in a well-ventilated, bunded and locked area of the building. Inert absorbent material will be stored in close proximity to aid in the event of a spillage.

Small quantities of water will be required for various parts of the process, including making up the 60% water in the amine solution. There will also be use of demineralised water for the water wash within the amine system. However, this will be continuously recycled and therefore there will not be any deliveries or storage outside of the amine system itself.

Table 4: Raw material consumption

Raw material	Storage Arrangements	Handling Requirements	Annual Consumption (tonnes per annum)	Environmental Effects	Alternatives
Biomass (Waste wood See Table 3 for EWC codes)	Stored under cover in the building to keep dry	No specific handling requirements	2,800	No adverse environmental effects from the types of waste wood accepted (Grade A).	Virgin wood will also be tested at the site.
Demineralised water	Stored in sealed container	No specific handling requirements	Very small amounts	No adverse environmental effects expected due to the low amounts to be used	Recycled water – however, this increases energy and chemical usage
Methyldiethanolamine (MDEA)	Stored in sealed container under well ventilated, locked, area. Chemical will be stored in ISO container and bunding with a capacity of 110% of the largest container. Inert absorbent material will be stored in close proximity.	Wear personal protective equipment/face protection.	8	Readily biodegradable. Under certain conditions the substance can form nitrosamines. Nitrosamines are carcinogenic in animal studies. Avoid dispersal of spilled material and runoff and contact with soil, waterways, drains and sewers.	Alternative reagents have higher handling risks and alternative processes have not been tested at this scale.
Piperazine (PZ)	Stored in sealed container under well ventilated, locked, area	Corrosive material – wear protective gloves when handling Wash face, hands and any exposed skin	2	Stable under normal conditions, but light sensitive. PZ is corrosive. It is soluble in water.	Alternative reagents have higher handling risks and alternative processes have not

	Avoid exposure to light, moisture and sources of ignition. In the event of a spillage, sweep up and shovel into suitable containers for disposal. Remove all sources of ignition	thoroughly after handling. In case of inadequate ventilation wear respiratory protection.			been tested at this scale.
Water (primarily for amine make-up)	Stored in sealed container	No specific handling requirements	100	No adverse environmental effects	Recycled water – however, this increases energy and chemical usage

3.1.4 Pyrolysis & combustion

The dried feedstock is automatically fed into the pyrolysis unit from underneath into a central pile on the floor of the combustion chamber. Different waste wood types will be stored and fed into the process separately to improve control of combustion conditions. The volume of air is accurately controlled to ensure effective pyrolysis. During the process the wood is pyrolised into biochar and syngas. The biochar is collected for distribution, whilst the syngas is combusted to generate high temperature flue gas.

3.1.5 Hot air turbine

The resulting hot flue gas is passed through a heat exchanger which is used to raise the temperature of air taken into the process at ambient conditions. This heated air is used within the hot air turbine (operating as part of a Brayton cycle) to generate heat and power.

3.1.6 Steam generation & heat recovery

The flow of clean hot air out of the hot air turbine is directed to the steam generator where the heat is used to raise steam for use in the stripper reboiler. This is the most significant heat use within the amine system. The design has been optimised to minimise the reboiler heat requirements.

After exiting the steam generator, the hot air is directed in two ways: one fraction of the air flow is returned to the pyrolysis unit where it is used to heat the unit to the temperatures required for pyrolysis, the second fraction is passed into an air-water economiser.

3.1.7 Flue gas scrubbing

Flue gas exiting the hot air turbine heat exchanger is passed through a flue-water economiser before being directed through a scrubber. During this cleaning process particles, contaminants and acid gases are absorbed into the scrubbing water. Lime is dosed into the scrubbing water as required to maintain a neutral pH which neutralizes the acids absorbed from the flue gases. As the gases leave the scrubber, they pass through a mist trap to remove any water vapour from the flue stream prior to entering the amine CO_2 removal plant. The scrubbing water is continuously circulated through a hydro-cyclone to separate the captured particulates from the water prior to being pumped back into the scrubber.

The subsequent R&D amine cycle is only designed to remove CO_2 from the flue, and hence this scrubbing process is critical to ensuring stack pollutants are controlled and within regulatory standards. Furthermore, the presence of the pollutants in the flue can decrease the ability of the amine solvent to remove CO_2 from the flue.

3.1.8 Amine cycle

In the BIOCCUS pilot plant, one quarter of the flue gas stream will pass through the amine cycle to demonstrate effectiveness of the carbon capture system. Once the redirected stream has passed through the amine cycle it will re-join the main flue gas stream and exit the stack.

An overview of the Amine cycle is shown below in Figure 5.

The flue gas from the upstream system is first cooled before entering the ~10m high absorption column. A blower is deployed to overcome the pressure gradient throughout the column.

Inside the absorption column, the CO_2-rich flue gas travels up the absorption column, flowing counter current to the amine solvent, capturing a large proportion (approximately 80%) of the CO_2 in the flue gas. Additional carbon is captured in the biochar, which leads to a very high overall carbon capture rate for the whole system. Methyldiethanolamine (MDEA) is the amine selected for use within the system. Piperazine (PZ) will also be added to this solution to enhance the ability of the solvent to remove CO_2 from the flue. Flue gas that has had most of the CO_2 removed exits at the top of the absorption column and is released to the atmosphere via the stack. The stack will incorporate periodic monitoring, but for process development purposes will also use a CEMS (Continuous Emissions Monitoring System). A water wash section is located at the top of the absorber to reduce the quantity of amine and aerosols that are lost from the absorber into the flue gas. Based on the modelling undertaken so far, this approach is considered to be sufficient to achieve the relevant ELVs for each emission, including NOx. As this project is for R&D purposes, should the monitoring equipment detect a problem or breach of the ELVs, testing will stop, the feedstock will be removed and the design will be adjusted accordingly.

After leaving the bottom of the absorption column, the CO_2-rich amine solvent is fed into the stripping column. The solvent is heated via a reboiler using steam from the steam generator. Inside the stripping column, the CO_2 contained in the amine solvent is released and exits at the top of the column as a CO_2-rich gaseous stream. Following the stripping column, the CO_2 stream is further purified. Initially, the CO_2 will be released to the atmosphere from the same flue stack as the rest of the flue gases. However, it is intended to find an alternative route in which the CO_2 will be used in a process such as concrete manufacture.

At the bottom of the stripping column, the lean solvent is pumped back into the absorption column through a series of heat exchangers that bring its temperature down to absorption conditions, completing the amine cycle. The first heat exchanger allows the recovery of part of the energy, pre-heating the stream entering the stripping column. The formation of heat stable salts (HSS) will be evaluated with various feedstocks as part of the development work. The combustion temperatures required for biochar production mean that no NOx is generated from the air; there will only be nitrogen present that was already present within the feedstock. Hence the levels of NOx generated are expected to be very low, without any additional NOx abatement.

At present, amine absorption systems use large quantities of heat to drive the capture cycle. BIOCCUS will use the heat output from the hot air turbine, CHP units, and flue gas to 'drive' the amine cycle while leaving surplus electricity and heat available to be exported.

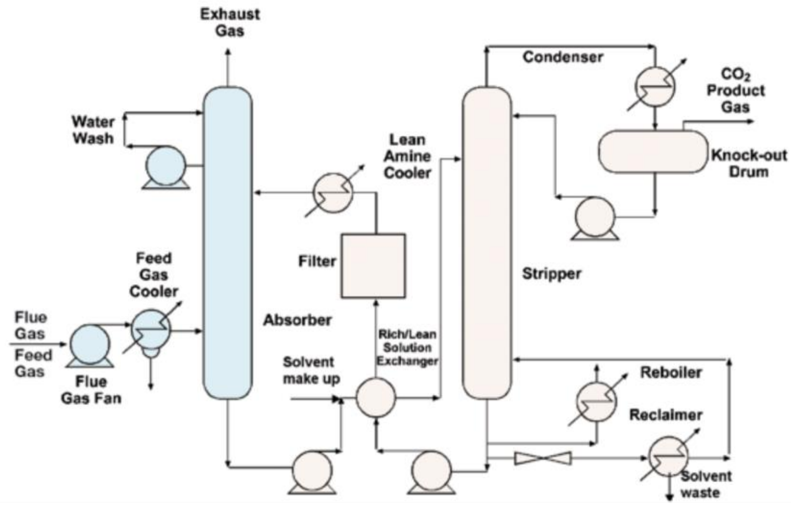

Figure 5: Process Flow Diagram for Post-Combustion Carbon Capture with Amine Solvent[2]

3.1.9 Biochar handling

Following production in the pyrolysis stage, the biochar is automatically drawn out at the periphery of the chamber and requires cooling, sorting, and bagging. The pyrolysis system will produce 70 kg/h of Biochar (dry weight) and represents ~50% of the carbon captured by the plant. This equates to 560 tonnes of biochar over 8,000 hours of operation. The hot biochar is dropped into a wet sump to quench the product before it is further processed and packaged. The biochar will be packaged on-site in the biochar handling plant, immediately after removal from the wet sump. Up to 20 tonnes will be stored on-site, short-term, before being collected for use as a soil improver, in anaerobic digestors or as a supplement for animal feed.

[2] IPCC Special Report on Carbon Dioxide Capture and Storage. Available at: https://www.ipcc.ch/site/assets/uploads/2018/03/srccs_chapter3-1.pdf

3.1.10 Wastewater

The amine solvent process will lead to the generation of contaminated water effluent. The amine carbon capture system is a continuous process in which the amines are repeatedly exposed to high temperatures. This leads to the degradation of the amines. It is for this reason the solvent must be regularly purged from the system. This purged effluent cannot be discharged to the sewers, instead it will be temporarily stored onsite and collected weekly by a third-party waste contractor for disposal offsite. Approximately 1-2 tonnes will be stored on site at any one time.

3.1.11 Continuous emissions monitoring

The implementation of CEMS aims to ensure that the waste combustion plant does not operate outside its emission limitations and assist in the process development of the R&D facility. The CEMS will monitor the following parameters: Carbon Monoxide, Nitrogen Oxides, Sulphur Dioxide and Ammonia, for internal monitoring purposes only.

3.2 Technical Standards

The proposed facility primary activities are the pyrolysis of dried biomass and the combustion of the subsequent syngas within the hot air turbine which is subject to the Environmental Permitting Technical Note 5/1(18) reference document for the incineration / combustion of waste wood. The amine carbon capture system requires an assessment of the proposed operating techniques against the post-combustion carbon capture BAT guidance.

As such, the key technical standards laid out in the following documents govern the design and operation of the Site:

- The Environmental Permitting Regulations 2016 (as amended)
- Post-combustion carbon dioxide capture BAT
- Developing a management system: environmental permits
- Controlling and monitor your emissions for an environmental permit
- Medium combustion plant and specified generator regulations

3.3 Management Techniques

3.3.1 Summary of Environmental Management System

Ricardo will operate an Environmental Management System (EMS) that complies with the requirements of EA guidance which will be in place before commencement of operation. The EMS will be continually reviewed, at least annually and in response to any changes to the site, including but not limited to: operations or equipment (including permit variations), any accident, complaint, or breach of the permit.

In summary, the EMS will include the following key elements to comply with the requirements defined in the Environmental Permitting Technical Note 5/1(18) reference document for the incineration / combustion of waste wood:

- Cleaning and maintenance
- Staff training
- Plant operation
- Waste acceptance criteria
- Bottom ash storage and disposal
- Emissions monitoring
- Plant failures
- Record keeping on all of the above

As per the requirements from the reference document for the incineration or combustion of waste wood, the operator will ensure records are kept for a minimum of 6 years.

3.3.2 Management Structure & Responsibilities

The Director of Plant Operations is responsible for day-to-day operations, with the SHEQ Manager responsible for compliance with the environmental permit.

The site will be managed using sufficient competent persons and resources to ensure that the site operates in accordance with site rules and operating procedures, and that conditions of the environmental permit are met.

The specific management structure is yet to be finalised but will be included in the EMS and will be in place before commencement of the plant.

3.3.3 Staff Training

All plant will be operated in accordance with the manufacturers' operating manuals to ensure safe operation and minimise emissions. Where there is no manufacturer's operating manual, an operating procedure manual will be developed and will include procedures on how to deal with plant failures.

All staff employed at the facility will benefit from a training programme and only trained staff will operate the plant. The assessment of training needs will be reviewed on an annual basis. The training programme will maintain the awareness of the environmental permit and EMS for all relevant staff. New employees will be given full induction training by managerial staff or other appropriately qualified persons. All staff will be trained in how to handle a spill that occurs on site and in the actions required in emergencies and abnormal operations.

Records will be kept of all staff qualifications and training in relation to operation of the processes at the site, emergency protocols and the content and requirements of the environmental permit and its management plans.

Where works are contracted to a third-party, they will have undergone an assessment during the procurement process to determine technical competency and to satisfy training standards. All persons attending site will receive a comprehensive site induction detailing site rules, emergency procedures and specific site hazards as set out in Construction (Design and Management) 2015 regulations.

3.3.4 Site Maintenance

Effective preventative maintenance and cleaning is a key component of operational control, particularly for ensuring emissions are minimised below required limits and energy efficiency is maximised. A maintenance schedule for the facility will be developed before the plant begins operation, detailing routine maintenance and planned downtime to reduce the risk of unexpected abnormal conditions or reactive maintenance issues arising. All aspects of the process, including all plant, buildings and equipment, including flues and ductwork will be maintained in line with manufacturers' recommendations. Where there are no recommendations, a maintenance procedure will be developed.

3.3.5 Noise Management Plan

As was set out in the pre-application advice, a noise impact assessment and noise management plan are not required to be submitted. However, a noise impact assessment is being carried out as part of the planning application.

3.3.6 Odour Management Plan

As was set out in the pre-application advice, an odour management plan is not required to be submitted.

3.3.7 Habitat Assessment

A Habitat assessment is not required; however, Ricardo are in discussions with an ecologist on the subject. This will ensure that no damage to local habitats occur because of the operation of this system.

3.3.8 Energy Efficiency

The estimated net power generation for the facility is presented in Table 5. Power is generated as both heat and electricity from the hot air turbine, and some is consumed parasitically in other areas of the plant, detailed in Table 6. Electricity will be drawn from the Grid for start-up, which will involve the use of approximately 50kW for less than 1 hour.

Table 5: Heat and power consumption

	Heat (KWth)	Electricity (kWe)	Total output (kW)
Demand	-192	-38.4	-230.4
Generated	+350	+80	+430
Net	**+158**	**+41.6 to 56**	**+199.6**

* Positive numbers within the table denotes net output in energy generation

Table 6: Parasitic Loads

Source	Parasitic Load (KWe)
Hot air turbine	2.6
Dryer and feedstock conveyors	5
Pyrolysis and biochar bagging	3.5
ID fans and flue gas scrubber	11.8
CHP system	0.3
Amine cycle	3.6
CO2 conditioning	3.1
Remaining balance of plant	2.5
Total	**32.4**

3.3.9 Avoidance, Recovery and Disposal of Wastes

The amount of waste generated has been minimised through design optimisation. Both solid and liquid wastes will be produced during operation of the facility, these include: biochar (solid), amine stream purge (liquid), amine-rich wastewater residues (solid).

As the facility will be producing these wastes in relatively small quantities, all wastes will be stored safely onsite and will be removed by a licensed waste contractor periodically.

More details of the biochar are provided in section 3.1.9.

More details of the amine stream purge are provided in section 3.1.10.

Solid amine-rich wastewater residues will be produced from the carbon capture element of the plant. The exact nature and quantity of these residues is not yet known as the carbon capture design has not been finalised and is a prototype system. However, these residues will be generated in small quantities, which will be stored in the building and collected by a licensed third-party waste contractor for disposal. The method of containment will be designed for the nature of the residues.

Records of all wastes removed from the facility will be recorded, held securely, and made available for inspection by the EA upon request. Should any new waste streams be generated during either normal or abnormal operations, the operator will apply the principles of the Waste Hierarchy prior to removal from site.

3.3.10 Accident Prevention and Emergency Protocols

Measures are in place across the site to reduce the likelihood of accidents. Automatic process controls are backed up by manual supervision by trained staff. The purpose of such controls is both to minimise the frequency of emergency situations and to maintain control during emergency situations.

3.3.11 Start-Up and Shutdown Procedures

The procedures for start-up and shutdown of the plant will be in place prior to commissioning of the plant. The plant will be designed and operated to ensure that there is no significant environmental or safety impact from start-up or shutdown, including in emergency scenarios.

3.3.12 Decommissioning and Closure

It is the Operator's responsibility to produce a Site Closure Plan in line with EA guidance when notified of the facility's date to cease operation. The Site Closure Plan will detail how the site will be decommissioned to return it to a satisfactory state upon the end of operation. Records will be maintained of the location of facilities and infrastructure, as well as the services and sub-surface structures installed during the operating phases of the facility.

Decommissioning will be performed in compliance with procedures outlined in a Site Closure Plan. During the decommissioning process, operational records will be reviewed and assessed against the Site Condition Report documented in this permit application. If areas of deterioration during the operation of the site are identified these areas will be remediated as appropriate and the site will be returned to a satisfactory state as defined at the permit application.

4 Emissions & Monitoring

4.1 Point source emissions to air

The pre-application advice stated that an air quality assessment must form part of the application process. Pollutants to be considered in the air quality assessment include:

- All the pollutants attracting an emission limit according to the Environmental permitting technical guidance PG5/1(21), see Table 7.
- All the emitted pollutants with a potential to cause acidification or nutrient nitrogen deposition to habitat sites.
- All the pollutants emitted as the result of amine-based carbon capture process, including ammonia, amines and their degradation products (e.g. nitrosamines).

In a subsequent discussion with the EA on 14th March 2023, it was agreed that the carbon capture activity would fall under the R&D exemption. However, as part of this R&D phase, the emissions from the process will be monitored in order to improve understanding of the carbon capture process used.

Where applicable, the facility must operate in accordance with the Environmental Permitting Technical Note 5/1(18) reference document for the incineration / combustion of waste wood, as well as the BAT guidance for PCC.

The control and monitoring of emissions to air will be in accordance with the EA's guidance on "Monitoring stack emissions: measurement locations" and "Monitoring stack emissions: techniques and standards for periodic monitoring". The emission limit values (ELVs) and monitoring frequencies for BIOCCUS are taken from the Environmental Permitting Technical Guidance Note (TGN) 5/1(18) reference document for the incineration / combustion of waste wood, where applicable, and from the Large Combustion Plant BAT Reference document (LCP BREF) and evidence from other CCUS projects for the emissions limits for carbon capture-specific emissions. The monitoring requirements stated in TGN 5/1(18) will be met. In addition, the following parameters will be monitored by CEMS for internal purposes only and will not be accredited: Carbon Monoxide, Nitrogen Oxides, Sulphur Dioxide, Ammonia.

Table 7: Monitoring requirements for BIOCCUS

Substance / parameter	Emission point	ELV (mg/Nm^3)	Minimum monitoring frequency	Standard
Carbon Monoxide	A1	225	Annual extractive	EN 15058
Dust	A1	50	Annual extractive	EN 13284-1
Oxides of Nitrogen	A1	500	Annual extractive	EN 14792
Total Volatile Organic Compounds (TVOC)	A1	30	Annual extractive	EN 12619
HCN*	A1	7.5	Annual extractive	US EPA OTM29
Formaldehyde**	A1	7.5	Annual extractive	A modified version of US EPA Method 316 is the preferred method for measuring formaldehyde, a CEN standard is near to publication

Smoke	A1	Ringelmann Shade 1	Daily when in operation	Ringelmann scale – BS 2742:2009 (Operator assessment)
Sulphur dioxide	A1	No ELV for this activity	At least every 3 years	EN 14791
Ammonia	A1	3	Annual extractive (FTIR)	EN 14791
Acetaldehyde	A1	5.3	Annual extractive (FTIR)	To be agreed with EA
Amines (as MDEA or DMA)	A1	20	Annual extractive (FTIR)	To be agreed with EA
NDMA	A1	0.002	Annual extractive (FTIR), if required	To be agreed with EA

*HCN monitoring is only applicable when melamine faced woods are in the fuel

**Formaldehyde monitoring is only applicable when plywood, chipboard and fibreboard woods are in the fuel.

As detailed in the Environmental Permitting Technical Note 5/1(18) reference document for the incineration / combustion of waste wood, the emission limits values given in Table 7 apply during normal operating conditions. It is expected that emission limit values will be met from the point when waste wood is first introduced into the process and so an auxiliary burner is not required.

The operator will carry out emission measurements within 4 months of the permit being granted or at the start of operation, whichever is later. Emissions will be recorded at multiple sampling points, corrected to standard reference conditions and submitted to the EA at the required frequency in accordance with the environmental permit.

4.2 Point source emissions to water

There will be no point source emissions to surface water, sewer or groundwater under normal operating conditions. As the site is an enclosed building, there will also be no surface water runoff to manage as any water/liquid will be contained within the building prior to collection for disposal/treatment.

Purged amine effluent will be temporarily stored in bunded ISO containers onsite and collected by a third-party waste contractor for disposal offsite. Approximately 1-2 tonnes will be stored on site at any one time.

4.3 Point source emissions to land

There will be no point source emissions to land.

4.4 Monitoring during commissioning

A commissioning plan will be produced and agreed with the EA, which will set out the procedures for commissioning, the tests to be carried out, the frequencies to benchmark performance and the acceptance criteria to be used. Following satisfactory completion of commissioning, sampling will be carried out at the frequencies specified in the environment permit.

4.5 Fugitive emissions

Good housekeeping practices on site will ensure that any spillages of potentially dusty materials are cleared up at the earliest opportunity. Spill kits will be located close to the relevant storage area(s) and/or delivery points. Spill kits will be available for clean-up of all chemicals, oils and liquid reagents stored and used within the plant. The amounts stored will be limited as detailed in Section 3.1.3. The actions to be taken in the event of a spillage will be set out in the site procedures.

Other potential fugitive emissions, such as those to surface water, are likely to be only due to accidents or incidents. Procedures for visual inspection of bunds will be in place to check for damage and accumulation of rainwater.

5 Impacts

5.1 Emissions to Air

A detailed modelling assessment has been carried out to assess the impact of the pilot BIOCCUS project on local air quality and is provided in Appendix A3 to this application.

The assessment has used the dispersion model ADMS 5.2 to predict the increases in pollutant species released as a result of the emissions released during the operation of the Facility, using best practice approaches. The assessment has been undertaken based on several worse case assumptions including assuming that the facility would emit continuously at the emissions limits, however, emissions from the pilot study is expected to be much lower than the emissions limit.

We have also provided an indicative assessment in Appendix A3 to quantify potential impacts from the onsite carbon capture process based on the best available data for ELVs, bearing in mind that there is significant uncertainty around potential emissions as this is a novel process. Should the operator wish to continue with the use of carbon capture beyond the R&D phase, this assessment would be updated with onsite monitoring data and any relevant published EALs as part of the permit variation application.

The results of dispersion modelling indicate that Process Contributions and resultant Predicted Environmental Concentrations of all pollutants at human receptors are of negligible significance, except for benzene and NO2 with a minor to moderate significance. However, this occurs at only four receptors out of the 41 receptors. Furthermore, the predicted environmental concentration at these receptors is well below the AQO and EAL (less than 70%).

Given that several worse case assumptions have been adopted, it is expected that overall, the effects of the proposed Facility are likely to be of negligible significance.

6 BAT Assessment

Table 8: BAT Assessment of the reference document for the incineration or combustion of waste wood

Reference	Environmental permitting technical guidance PG5/1(21) BAT Requirement	Response
Acceptable waste to be burnt		
4.1.1	Only clean wood waste, as described in 4.1.2, should be incinerated or combusted in a 5.1 Part B appliance.	Waste acceptance criteria, as set out in Section 3.1.1
4.1.2	All movement of waste (including wood waste) must be accompanied by a note, including: • a written description of the waste signed by you and the person you are buying from or selling to. • the waste classification code.	Waste acceptance criteria, as set out in Section 3.1.1
Plant design and operation		
4.2.1	Variation in fuel size and moisture content limits the ability of combustion control systems to give good combustion. Fuel with a narrow size and moisture distribution burns much better than mixed-size fuels or fuel of variable moisture level. Operators should: • store fuel under cover to keep fuel dry • store and feed different waste wood types (for example offcuts, briquettes, woodchips and dust) separately to improve control of combustion conditions	See Section 3.1.2 and 3.1.4
4.2.2	Automatic fuel feed systems prevent the emission of smoke fumes and reduce the emission of other pollutants. For existing processes, use automatic feed systems wherever practical. For new processes, use automatic fuel feed systems.	See Section 3.1.2 and 3.1.3
4.2.3	On start up from cold, before waste wood is put into the furnace, raise the combustion zone temperature, using an ancillary burner fired by natural gas, gas oil, or virgin wood. Do not burn waste wood during the start up from cold. When the burner is idling, carbon monoxide concentrations can rise significantly. While in many cases it is technically feasible to prevent idling, in a few cases it may only be possible to minimise it. Where this is not technically feasible, operators must justify this to the regulator	There are currently no planned burners for the project as they are not necessary for the normal operation of the process, given it is a demonstration plant. Installed CEMS will monitor emissions, if issues are encountered with emission limits then a burner will be installed accordingly.
4.2.4	Good combustion requires good management and control of a number of parameters: • fuel content and its rate of feed • primary and secondary air • temperature in the combustion chamber and the heat exchanger • oxygen levels	Waste acceptance criteria, as set out in Section 3.1.1 The combustion controller is a key controller within the system that controls the following to produce biochar of the correct quality in a safe manner: • Feedstock flow rate

Reference	Environmental permitting technical guidance PG5/1(21) BAT Requirement	Response
		• Primary, secondary, tertiary air flow. Pyrolysis occurs through radiation of heat from the combustion chamber directly above it. The hot air turbine controller manages the heat exchanger by-pass valve to regulate the temperature into the turbine and prevent the power turbine from exceeding its rating. In addition, the controller monitors a variety of temperatures and pressures to check the system remains in a healthy condition and provides early warning of possible defects.
4.2.5	Good control of air flow is essential to thermal efficiency. More air than the theoretical minimum is required for stable combustion and to prevent the formation of carbon monoxide (CO). Excess CO is a good indicator of incomplete combustion. Too much excess air will increase the carryover of dust and lower temperature, resulting in a loss of thermal efficiency. Some biomass combustion plants may have re-circulated flue gases to ensure optimum combustion, with minimum excess air. Flue gas recirculation will also help reduce emissions of nitrogen oxides (NOx).	The combustion controller regulates and controls primary, secondary and tertiary air flow. For flue gas recirculation, see Section 3.1.7
4.2.6	Normally, the combustion gases are then directed into a boiler section to produce hot water, steam or heat thermal fluid (for example hot oil). The energy produced might be used for process heat, building or district heat, electricity or for combined heat and power. A good turndown ratio (that is the ratio between maximum and minimum firing rates, over which emission parameters can be satisfied) will enable greater thermal efficiency by better matching the heat requirement with the waste wood feed rate.	Process design has maximised heat recovery throughout the system, see Section 3.1.6. As it is an R&D facility, the plant will not need to be kept running at idle as there are no output heat or power requirements. The plant will be able to run at part-load. Currently, the minimum load is expected to be approximately 25%. Not applicable for BIOCCUS as syngas is passed through a Hot Air Turbine rather than a boiler to generate heat and electricity.
Air quality, dispersion and dilution		

	Environmental permitting technical guidance PG5/1(21)	
Reference	BAT Requirement	Response
4.4.1	Pollutants emitted via a stack need sufficient dispersion and dilution in the atmosphere. This ensures that they do not ground at concentrations which may be harmful to human health or the quality of the environment.	See Appendix A3 Air Quality Assessment
4.4.2	Emissions to air should be free from dark smoke and from offensive odour outside the site boundary, as perceived by the regulator. This can be achieved by good combustion.	Smoke will be monitored in accordance with ELVs. See section 4.1 An odour assessment is not required as set out in the pre-application advice, see Section 1.3
4.4.3	All new and replacement plants must submit an air quality report detailing the long-term and short-term process contribution as part of their application.	See Appendix A3 Air Quality Assessment
4.4.4	Emissions from the permitted process must not cause or contribute to: • EU air quality limit values being exceeded • the values within the objectives of the Air Quality Strategy for England, Scotland, Wales and Northern Ireland for sulphur dioxide, oxides of nitrogen and particulate matter (PM10 and PM2.5).being exceeded	As per BAT 4.4.3, above, an air quality assessment is being submitted as part of the application. BIOCCUS will operate in accordance with the required ELVs, see Section 4.1. These will be monitored according to the relevant required frequency and standards, with some emissions monitored additionally by CEMS, see section 3.1.10, ensuring the ELVs are not breached.
4.4.5	The regulator will impose tighter emission limits than those set out in BAT if: • air quality standards or objectives are being breached or are in serious risk of breach • it's clear from the air quality report or detailed review and assessment (for existing installations) that the permitted process itself is a significant contributor to the problem, (see BAT 4.4.6) The need for tighter emission limits might be offset, fully or in part, by increasing the stack height or exit velocity.	n/a
4.4.6	Ensure that the process contribution is no more than 1% of the relevant long-term Environmental Quality Standard (EQS) and/or 10% of the relevant short-term EQS at sensitive receptors. Where this cannot be demonstrated through simple calculations, (for example the air risk assessment in BAT 4.4.3), the operator will need to use computer-based air dispersion models, for example ADMS (Advance Dispersion Modelling System), AERMOD (Atmospheric Dispersion Modelling) or some form of intermediate screening tool.	See Appendix A3 Air Quality Assessment

	Environmental permitting technical guidance PG5/1(21)	
Reference	BAT Requirement	Response
	When calculating the impact of particulate emissions (PM10 and PM2.5), data on particle size distribution of dust emissions may be needed. Otherwise, assume that all the dust emissions are present as PM10 or PM2.5.	
4.4.7	To ensure dispersion is not impaired by either low exit velocity at the point of discharge or deflection of the discharge: • the stack exit should be vertical • do not use a cap or other restriction A cone may sometimes be useful to increase the exit velocity to achieve greater dispersion.	See Appendix A3 Air Quality Assessment The stack exit is vertical and does not use a cap or other restriction
4.4.8	Where necessary, the regulator will include the minimum stack height or exit velocity within the environmental permit.	The Air Quality assessment is based on a stack height of 10.6m
Abatement		
4.5.1	Good combustion techniques minimise dust emissions. Dust includes emissions of particulate matter of all particle sizes, for example PM10 and PM2.5). Poor combustion control, for example high temperatures and insufficient oxygen, will increase dust emissions. Where necessary, in order to reduce dust emissions to air to meet ELVs, operators must install abatement.	BIOCCUS will operate in accordance with the required ELVs, see Section 4.1, through appropriate process control, see Section 3.1.3 For flue gas abatement, see Section 3.1.7 and 3.1.8
Emission testing		
4.6.1	Where annual emissions testing is required, the operator must have suitable and sufficient monitoring locations for testing. Guidance on testing locations is in the Environment Agency's Technical Guidance Note (Monitoring) M1: Sampling requirements for stack monitoring. The operator is advised to work with an emissions testing company before applying for a permit to ensure emissions monitoring can be carried out. Operators who comply with the Environment Agency's Monitoring Certification (MCERTs) scheme for environmental permit holders, will meet the monitoring requirements of this guidance.	BIOCCUS will be operating monitoring systems in accordance with required frequencies and standards with additional CEMS monitoring where possible, see section 3.1.10 and 4.1.
4.6.2	If considered necessary, the regulator should include permit conditions detailing the requirements for periodic emissions testing, for example design and access.	BIOCCUS will have periodic monitoring, with additional CEMS monitoring also, see section 3.1.10 and 4.1.
4.6.3	Where emissions monitoring is required but cannot be safely or correctly carried out, the regulator should refuse the permit.	n/a
Management		
4.7.1	Effective management is central to environmental performance; it's an important component of BAT and in complying with permit conditions.	See Section 3.3.1

	Environmental permitting technical guidance PG5/1(21)	
Reference	BAT Requirement	Response
	Operators of installations should put in place a structured Environmental Management System (EMS) to cover: • cleaning and maintenance • staff training • plant operation • waste acceptance criteria • bottom ash storage and disposal • emissions monitoring • plant failures • record keeping If the operator already has accreditation to a published standard (such as ISO 14001), they do not need to set up a separate system. Regulators should use their discretion, in consultation with individual operators, to agree the appropriate level of EMS for the nature and size of the particular process.	
Cleaning and Maintenance		
4.8.1	Effective preventative maintenance and cleaning is important to comply with emission limits.	See Section 3.3.4
4.8.2	Clean flues and ductwork regularly to ensure that a build-up of material does not affect emissions and their dispersion.	See Section 3.3.4
4.8.3	Maintain all aspects of the process, including all plant, buildings and equipment, in line with manufacturer's recommendations. Where there are no manufacturer's recommendations, the operator should develop their own maintenance procedures.	See Section 3.3.4
Training and Operation		
4.9.1	All plants should be operated in accordance with the manufacturer's operating manual to minimise the risk of emissions. Where there is no manufacturer's operating manual, develop your own operating procedures which should include procedures on how to deal with plant failures.	See Section 3.3.3
4.9.2	Only trained staff must operate the plant.	See Section 3.3.3
Waste acceptance criteria		
4.10.1	The operator must have procedures in place to ensure that only waste wood listed in BAT is incinerated/ combusted.	Waste acceptance criteria, as set out in Section 3.1.1
4.10.2	Where an operator is incinerating or combusting their own waste wood arisings, they must demonstrate that the waste wood conforms to that in BAT.	Not applicable to BIOCCUS. Waste wood is to be supplied by 3rd party contractor.
4.10.3	All imported waste wood must be accompanied by the relevant written information, as set out in BAT 4.1.2, which will: • include the European Waste Classification Code • show that the wood is untreated • show that the wood has been kept separate from wood that might contain halogenated organic compounds or heavy metals as a result of treatment with wood preservatives or coatings	See section 3.1.1
4.10.4	The regulator should check all duty of care written descriptions of waste routinely as part of their programmed inspection.	See section 3.1.1

Reference	Environmental permitting technical guidance PG5/1(21) BAT Requirement	Response
Bottom ash storage and disposal		
4.11.1	All incineration/combustion of solid fuels results in some bottom ash being produced. The operator should control this correctly, to avoid ash escaping off site. This could be something as simple as a well-lidded bin.	The pyrolysis process produces biochar, which is automatically removed from a chamber, cooled, dried and then bagged.
4.11.2	The furnace should be designed to minimise the time the operator needs to access the combustion space for de-ashing. For new processes of 1MW thermal input or more, use automatic de-ashing systems. For existing processes, use automatic de-ashing systems where practical.	The biochar is automatically drawn out at the periphery of the pyrolysis chamber, see Section 3.1.9
4.11.3	Store and dispose of bottom ash in a way that prevents the escape of dusty waste (for example in covered containers, purpose-built silos or undercover).	The hot biochar is dropped into a wet sump to quench the product before it is further processed and packaged, see Section 3.1.9
Record Keeping		
4.12.1	The operator must keep written records of: • all inspections, both by external bodies and internal employees • maintenance, including cleaning, maintenance undertaken by external contractors or internal personnel and breakdowns • operating procedures with subsequent training records • emission testing, periodic and operator assessments as well as details of any testing platforms The regulator will inspect these records, and any relevant duty of care notes, as part of a site visit.	See section 3.3.1
4.12.2	For medium combustion plants, the operator must also keep a written record of: • the type and quantities of fuels used in the plant • information proving the effective continuous operation of secondary abatement equipment needed in order to meet the emission limit values • any malfunctions or breakdown of secondary abatement equipment	See section 3.3.1
4.12.3	The operator must keep records for a minimum of 6 years.	See section 3.3.1

Table 9: BAT Assessment of Post-Combustion CO_2 capture

Reference	Post-combustion carbon dioxide capture: best available techniques (BAT) BAT Requirement	Response
PCC plant design and operation		
3.1	The purpose of the PCC plant is to maximise the capture of CO_2 emissions for secure geological storage.	

Reference	Post-combustion carbon dioxide capture: best available techniques (BAT) BAT Requirement	Response
	You should aim to achieve a design CO_2 capture rate of at least 95%, although operationally this can vary, up or down. You should capture CO_2 during start-up and shutdown as part of using BAT. You will need to deliver CO_2: • at local transport system pressures (gas phase such as 35 bar or dense phase such as 100 bar) • with levels of water, oxygen and other impurities as required for transport and storage such as that for the system operator National Grid (NGC/SP/PIP/25 Dec.2019) The PCC plant must also have acceptable environmental risks through preventing or minimising emissions, or render them harmless. You must achieve environmental quality standards for air emissions from the PCC plant and their subsequent atmospheric degradation products (including, for example, nitrosamines and nitramines). You should confirm this using: o Atmospheric dispersion and reaction modelling tools o Specific site parameters which will define plant-specific ELVs Your PCC system design should aim to minimise the overall electricity output penalty on the power or CHP plants from all aspects of PCC plant operation, as much as possible. It should do this while meeting the CO_2 capture requirements set out in this guidance.	For the BIOCCUS demonstration plant, the captured carbon will not be stored, it will be released to the atmosphere via the stack. See Appendix A3 Air Quality Assessment
3.2	Solvent selection: The project-specific potential for absorber stack emissions and consequent environmental impacts will depend on the selected solvent. You should assess your plant design and operation, plus local environmental factors, based on: • direct emissions of solvent components • formation of additional substances in the PCC system and emissions of those substances • formation of further additional substances in the atmosphere from emissions from the PCC system The potential for solvent reclaiming and other cleaning methods is also an important factor in solvent selection. You should make sure it is practicable to remove all non-solvent constituents from the solvent inventory as fast as they are added during operation, to avoid accumulation. You should also make sure that you: • recover a high fraction of the solvent in the feed to the reclaimer during reclaiming • minimise reclaimer wastes and that they can easily be disposed of You must work out the solvent performance, including reclaiming requirements and emissions to atmosphere. Determine this through realistic pilot (or full scale) tests using fully representative (or actual) flue gases and power plant operating patterns over a period of at least 12 months.	The selection of MDEA as the amine went through a detailed analysis of the different types of amines. The comparison considered: the flue gas characteristics as well as solvent specific parameters including reaction rates, associated heat requirements and thermodynamic properties
Features to control and minimise atmospheric and other emissions		

<table>
<tr><th>Reference</th><th>Post-combustion carbon dioxide capture: best available techniques (BAT)
BAT Requirement</th><th>Response</th></tr>
<tr><td>3.3.1</td><td>Flue gas cleaning needs to consider the following:
SOx removal
NOx removal - If the amine blend will form significant amounts of stable nitrosamines with NOx in the flue gas, then you must reduce NOx to as low a level as practicably possible (see LCP BREF) using selective catalytic reduction (SCR).
Aerosols
Other flue gas impurities</td><td>See Section 3.1.7 and 3.1.8</td></tr>
<tr><td>3.3.2</td><td>PCC system operation:
Operating temperatures
You must establish and maintain optimum temperature and appropriate limits in the solvent stripping process.
Elevated temperatures can cause some thermal degradation of the solvent. But higher peak average temperatures during regeneration will also likely promote reduced energy requirements and higher CO2 capture levels. You must balance both to ensure the right environmental outcome.
Where feasible, you should avoid locally higher metal skin temperatures, such as from the use of superheated steam in heaters, as this provides no benefit and can result in degradation.
Solvent degradation
You should minimise oxidative degradation of the solvent by reduced solvent residence times in the absorber sump and other hold-up areas. Direct O2 removal from rich solvent may be developed in the future but has not yet been proven at scale.</td><td>Detailed modelling and design of the carbon capture system has yet to be finalised. BAT guidance will be followed where possible.</td></tr>
<tr><td>3.3.3</td><td>Absorber emissions abatement:
Water wash - you must use one or two water washes or a scrubber to return amine and other species to the solvent inventory.
Acid wash – should be implemented, unless:
Emission levels are already at acid wash levels with a water wash
You can show that the need to dispose of the acid wash waste outweighs the benefits of the additional reduction in emissions to atmosphere
Droplet removal – you must prevent emissions of aerosols
Stack height - Where modelling predicts that you may need to raise the temperature at the point of release to aid dispersion, you can:
increase the design stack height
add flue gas reheating</td><td>See Section 3.1.8
Emissions levels are expected to be reached without an acid wash. Droplet removal will occur through a demister at the absorber outlet. The AQ modelling (Appendix A3) concludes that there are no significant issues with stack height and release temperature.</td></tr>
<tr><td colspan="3">Process and emissions monitoring</td></tr>
<tr><td>3.4.1</td><td>Role of monitoring:
show that the emissions from the process, primarily to air, 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
Capture efficiency
Verification that the CO_2 product is suitable for safe transport and storage
Permit application should include a monitoring plan for both a commissioning phase and routine operation.</td><td>See Section 3.1.10 and 4 for monitoring of emissions to air.</td></tr>
</table>

Reference	Post-combustion carbon dioxide capture: best available techniques (BAT) BAT Requirement	Response
	• During the commissioning phase you will need to optimise the operating envelope for the process. When you have achieved this the process operation will then become routine, along with the monitoring. • You must also show that you're 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.	
3.4.2	Point source emissions to air: • You must include monitoring to demonstrate compliance with the IED Chapter III ELVs and the LCP BREF BAT AELs at normalised conditions. • You must also monitor for: ○ ammonia ○ volatile components of the capture solvent ○ likely degradation products such as nitrosamines and nitramines • Your monitoring may be by either: ○ continuous emissions monitoring ('on line') ○ periodic extractive sampling ('off line') – where aerosol formation is expected, this must be isokinetic	BIOCCUS project is exempt from IED and LCP BREF requirements due to the feedstock proposed and low capacity of the plant. Periodic monitoring of relevant emissions will be employed, with additional CEMS measurements, see Section 3.1.10 and 4
3.4.3	Process control monitoring: You should use process control monitoring or periodic sampling with off-line analysis to control the CO_2 capture and the quality of the solvent reclaiming. Parameters you can monitor include: • absorber solvent quality – percentage active solvent • CO_2 loading both rich and lean solvent • maximum solvent temperature • heat stable solvent content • solvent colour or opacity • soluble iron and other metals and degradation products • in water or acid washes and scrubbers – pH, conductivity, loading of abated substances, flow rate	The amine system will include monitoring of: • maximum solvent temperature • heat stable solvent content • pH • flow rate
3.4.4	Monitoring of CO_2: To meet the required specification, include: • CO_2 mass balance • CO_2 in fuel combusted • total capture level (as a percentage) • CO_2 released to the environment • CO_2 quality	Due to the R&D nature of the project, there are no requirements to monitor CO_2. Carbon in the feedstock and biochar will be regularly sampled. CO_2 separated from the flue gas will be continuously monitored and a capture percentage can therefore be calculated. CO_2 quality will be measured and aims to be food-grade
3.4.5	Monitoring standards:	Periodic monitoring will be MCERTS certified. Any laboratory used for

Reference	Post-combustion carbon dioxide capture: best available techniques (BAT) BAT Requirement	Response
	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 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.	monitoring will be UKAS accredited. See section 3.1.11 and 4.1
Unplanned emissions to the environment		
3.5	You should propose a leak detection and repair programme that is appropriate to the solvent composition. This should use industry best practice to manage releases, including from joints, flanges, seals and glands. Your hazard assessment and mitigation for the plant must consider the risks of accidental releases to environment. This should also consider the actual composition of the fluids, gases and vapours that could be released from the plant after an extended period of operation. (Not only fresh solvent as initially charged.)	Detailed design of the carbon capture system has yet to be completed, including finalizing the hazard assessment. However, this will include a proposed release detection system and any mitigation deemed necessary.
Capture level, including during flexible operation		
3.6	Capturing at least 95% of the CO_2 in the flue gas is considered BAT. You can base this on average performance over an extended period (for example, a year). To achieve this, you should make sure the design capture level for flue gas passing through the absorber equates to at least 95% of the CO_2 in the total flue gas from the power plant. If you process less than the full flue gas flow, your capture rate will have to be correspondingly higher. Over the averaging period, your capture level may vary up or down. As the fraction of intermittent renewable generation in the UK rises, CCS power plants will need to start and stop more often, and possibly also operate at variable loads. It is therefore important that CO2 can also be captured at high levels during these periods, including during start-up and shutdown, to maintain high average capture levels. A method to maintain capture at normal rates or higher at all times using solvent storage has been identified in the BAT review. This, or alternatives that can achieve equivalent results, is considered BAT. If your PCC plant is not initially constructed with this capability, your permit application should show how you may retrofit it.	See section 3.1.8
Compression		
3.7	You should select CO_2 compressors based on the expected duty. You should consider how any waste heat arising may be used. For base load operation, you should use integrally geared units because they give the: • maximum full-load efficiency • minimum number of compression trains	This is not applicable as compression of CO_2 will not be carried out on site.

Reference	Post-combustion carbon dioxide capture: best available techniques (BAT) BAT Requirement	Response
	For flexible and part-load operation, smaller compression trains (for example 2 at 50% compared to 1 at 100%) may be preferable. The use of different types of compressor or pump in series may also be preferable, to give greater flexibility at the expense of slightly lower full-load efficiencies.	
Noise and odour		
3.8	The LCP BREF already covers noise impacts for the main power plant. You only need to consider additional process steps in PCC technology that have high potential for noise and vibration. In particular, CO_2 compression could be an area of concern. Once you've identified the main sources and transmission pathways, you should consider the use of common noise and vibration abatement techniques and mitigation at source wherever possible. For example, the: • use of embankments to screen the source of noise • enclosure of noisy plant or components in sound-absorbing structures • use of anti-vibration supports and interconnections for equipment • orientation and location of noise-emitting machinery • change of the frequency of the sound The handling, storage and use of 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.	Noise and odour assessments are not required for this activity. See section 1.2
Cooling		
4	You will be able to achieve the best power and CO_2 capture plant performance by using the lowest temperature cooling available. You should use the hierarchy of cooling methods as follows: • direct water cooling (such as seawater) • wet cooling towers • hybrid cooling towers • dry cooling – direct air-cooled condensers and dry cooling towers Power plants that are retrofitted with PCC using steam extraction, or are intended to be able to operate without capture, can share water cooling between the power plant and the PCC system. This is because the cooling load on the main steam condensers falls with increased steam extraction rate. This shift away from condenser cooling will not apply for systems with direct air-cooled condensers. It may also be possible to reuse cooling water after the main condensers for higher-temperature cooling applications in the PCC plant. However, site specific water discharge temperature limits may be an issue for direct cooling. A feature of PCC is that you have to remove heat from a flue gas stream that was originally not cooled. You can still achieve rejection of heat to atmosphere by heating the flue gas leaving the absorber, using heat from the incoming flue gas. You can do this either: • directly – such as using a rotary gas-gas heater • indirectly – such as using a heat transfer fluid or low-pressure steam	Detailed design of the carbon capture system has yet to be finalised, Direct water cooling is proposed to be used at the plant. The cooling water will be used in the feedstock dryer to achieve the required input moisture content. There will be no emissions to water. In most cases the cooling water will be able to be continually recycled. Any waste cooling water will be collected and transported off site for treatment/disposal.

	Post-combustion carbon dioxide capture: best available techniques (BAT)	
Reference	BAT Requirement	Response
	Lean and rich solvent storage may also help you achieve satisfactory PCC performance during periods of high cooling demand. You should refer to the Environment Agency's evidence on cooling water options for the new generation of nuclear power stations in the UK when considering options for cooling. This gives an overview of UK power station cooling water systems in use in the UK and abroad.	
Discharge to water		
5	For discharges to water, you should refer to the guidance on surface water pollution risk assessment for your environmental permit. For best practice in plume dispersal modelling, see the Joint Environmental Program report 'A protocol on projects modelling cooling water discharges into TrAC waters within power station developments'.	This is not applicable as there will be no discharges to water from this activity.
Climate change adaptation		
6	You must complete an adapting to climate change risk assessment as part of your permit application.	This is not applicable as the site is not expected to operate for more than 5 years.

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A1 Application Forms

Included in the attached file structure:

- BIOCCUS Application Form Part A v0.1.pdf
- BIOCCUS Application Form Part B2.5 v0.2.pdf
- BIOCCUS Application Form Part F1 v0.1.pdf

A2 Non-Technical Summary

Included in the attached file structure:

- BIOCCUS Permit Application Non-Technical Summary v2.1.pdf

A3 Air Quality Assessment

Included in the attached file structure:

- BIOCCUS Air Quality Assessment_Issue2.pdf

The folder entitled “Model input files” includes additional information regarding the approach and assumptions.

A4 Site Plans

Included in the attached file structure:

- Site Boundary and Emissions Points.png
- Site Layout.png

A5 List of Directors

Included in the attached file structure:

- List of Directors v1.0.pdf

A6 Pre-application advice

Included in the attached file structure:

- Application - Bespoke - Enhanced pre application advice letter.docx
- Environmental permitting technical guidance PG5_1 - Final Edit.pdf