Eggborough CCGT Project

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The Eggborough CCGT (Generating Station) Order
Land within and adjacent to the Eggborough Power Station site, Goole, East Yorkshire DN14 0BS

Carbon Capture Readiness Assessment

The Planning Act 2008

The Infrastructure Planning (Applications: Prescribed Forms and Procedures) Regulations 2009

Regulation – 5(2)(q)

Applicant: Eggborough Power Limited
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GLOSSARY

Abbreviation	Description
AGI	Above Ground Installation – installations used to support the safe and efficient operation of the pipeline
BAT	Best Available Techniques – the available techniques which are the best for preventing or minimising emissions and impacts on the environment. BAT is required for operations involving the installation of a facility that carries out industrial processes
BEIS	Department for Business, Energy and Industrial Strategy
CCGT	Combined Cycle Gas Turbine – a highly efficient form of energy generation technology. An assembly of heat engines work in tandem using the same source of heat to convert it into mechanical energy which drives electrical generators and consequently generates electricity
CCR	Carbon Capture Readiness – a power station is Carbon Capture Ready where it has been demonstrated that: sufficient space is available on or near the site to accommodate carbon capture equipment in the future; retrofitting carbon capture technology is technically feasible; that a suitable area of deep geological storage exists for the storage of captured CO2; transporting CO2 to the storage location is technically feasible and CCS is likely to be economically feasible
CCS	Carbon Capture and Storage – an emerging technology that enables carbon dioxide produced by burning fossil fuels to be captured and permanently stored, usually in deep geological formations, removing up to 90% of the carbon dioxide that would otherwise be released to the atmosphere
CO_2	carbon dioxide
COMAH	Control of Major Accident Hazards Regulations 1999 (as amended)
DCC	Direct Contact Cooler. A form of cooling applied to exhaust gases whereby gases are cooled through contact with a condensed liquid
DCO	Development Consent Order – made by the relevant Secretary of State pursuant to The Planning Act 2008 to authorise a Nationally Significant Infrastructure Project. A DCO can incorporate or remove the need for a range of consents which would otherwise be required for a development. A DCO can also include rights of compulsory acquisition
DCO Site	The site for which the DCO is sought. The Application Site.

DECC	Department for Energy and Climate Change – the UK government department responsible for issues regarding energy supply and climate change. This was replaced by the Department for Business, Energy & Industrial Strategy in July 2016
EPL	Eggborough Power Limited (The Applicant)
H&S	Health and Safety
HRSG	Heat Recovery Steam Generator – an energy recovery heat exchanger that recovers heat from a hot gas stream. It produces steam that can be used in a process (cogeneration) or used to drive a steam turbine (combined cycle)
HSE	Health and Safety Executive
IED	Industrial Emissions Directive EU Directive 2010/75/EU – European Union Directive committing member states to control and reduce the impact of industrial emissions on the environment
ISO	International Organization for Standardization – an international standard setting body composed of representatives for various national standards organisations
km	Kilometre
m	metres
MAHP	Major Accident Hazard Pipeline
MAPP	Major Accident Hazard Prevention Policy
MW	Megawatts
NPS	National Policy Statement – statement produced by Government under the Planning Act 2008 providing the policy framework for Nationally Significant Infrastructure Projects. They include the Government's view of the need for and objectives for the development of Nationally Significant Infrastructure Projects in a particular sector such as energy and are used to determine applications for such development
NSIP	Nationally Significant Infrastructure Project - defined by the Planning Act 2008 and cover projects relating to energy (including generating stations, electric lines and pipelines); transport (including trunk roads and motorways, airports, harbour facilities, railways and rail freight interchanges); water (dams and reservoirs, and the transfer of water resources); waste water treatment plants and hazardous waste facilities. These projects are only defined as nationally significant if they satisfy a statutory threshold in terms of their scale or effect.
NTS	Non-Technical Summary – a summary of the Environmental Statement written in non-technical language for ease of understanding
NYCC	North Yorkshire County Council
OCGT	Open Cycle Gas Turbine – a combustion turbine plant fired by liquid fuel to turn a generator rotor that produces electricity
PINS	Planning Inspectorate – executive agency of the Department for Communities and Local Government of the United Kingdom Government. It is responsible for determining final outcomes of town planning
Power Station site	The existing Eggborough Power Station site, comprising the land owned by EPL
SAC	Special Area of Conservation – high quality conservation sites that are protected under the European Union Habitats Directive, due to their contribution to conserving those habitat types that are considered to be most in need of conservation

SDC	Selby District Council
SoS	Secretary of State – the decision maker for DCO applications and head of Government department. In this case the SoS for the Department for Business, Energy & Industrial Strategy (formerly the Department for Energy and Climate Change).
SPA	Special Protection Area – strictly protected sites classified in accordance with Article 4 of the EC Birds Directive. Special Protection Areas are Natura sites which are internationally important sites for the protection of threatened habitats and species
SSSI	Site of Special Scientific Interest – nationally designated Sites of Special Scientific Interest, an area designated for protection under the Wildlife and Countryside Act 1981 (as amended), due to its value as a wildlife and/or geological site

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EXECUTIVE SUMMARY

The purpose of this assessment is to demonstrate that it would remain technically feasible to retrofit Carbon Capture technology in the future to the Eggborough CCGT project (the 'Proposed Development'). The assessment has been produced in accordance with the requirements of the Department of Energy and Climate Change (DECC) November 2009 carbon capture guidance "Carbon Capture Readiness (CCR) – A Guidance Note for Section 36 Electricity Act 1989 consent applications" The following approach has been used for this CCR assessment:

- the sizing and utility demand of the main CCS equipment that would be required including site layout drawings to show that the equipment would fit into the land currently identified to be retained for CCR purposes;
- geological storage sites with storage capacities capable of accepting the carbon output from the Proposed Development over its design life and Potential routes to transport the CO_2 to the those sites;
- an economic assessment for the CCS plant (including transport and storage) to estimate the price of EU allowances for CO_2 which are necessary to make the Proposed Development feasible with CCS; and
- a high level assessment of the Health and Safety issues associated with the CCS plant.

For the purposes of this assessment a power station plant configuration of 3 single shaft CCGT H Class units up to a maximum of 2,500 MW has been assumed. Exhaust gas data to allow the relevant space calculations to be undertaken based on the largest commercially available H class unit. Only post combustion carbon capture (amine based absorption) has been considered in this assessment as it the only technology capable of being retrofitted.

The conceptual design of the carbon capture system proposed for the Proposed Development has been based developed. At this stage, no detailed design of any potential CCS Plant has been undertaken and none would be undertaken until CCS was mandated to be required for the Site.

An indicative 'worst case' total footprint of the CCS plant was calculated from design principles at approximately 90,000 m^2, well within the space available and to be retained on Site (120,000 m^2). The footprint was used to prepare the plot plan that demonstrates that appropriate space has been allocated. The laydown area required during construction of the CCS equipment would be determined and secured at the time of installation and would depend on the year of construction.

The maximum theoretical volume of CO_2 anticipated to be captured during the lifetime of the Proposed Development is 223 million tonnes (assuming approximately 6.5 Mt CO_2/year from the three CCGT units, an average lifetime capacity factor of 90% and a 35 year design lifetime of the power station).

The UK's major potential sites for the long-term geological storage of CO_2 are offshore depleted hydrocarbon (oil and gas) fields and offshore saline water-bearing reservoir rocks / aquifers. The nearest hydrocarbon fields to the Proposed Development are located in the Southern North Sea Basin. The DTI's 2006 study of UK Storage Capacity "Industrial Carbon Dioxide Emissions and Carbon Dioxide Storage Potential in the UK", 2006 lists a number of storage options within the gas and condensate fields with the basin that could be use either individually or in combination to store the CO_2 from the Proposed Development. Of these fields, Indefatigable and Lemen could store the entire CO_2 production of the Proposed Development over its entire lifetime on their own. These fields are both listed as 'realistic' in the DTI Study.

It is proposed that the CO_2 captured from the Proposed Development will be transported to the storage site via pipeline. An assessment of an indicative route has been assessed taking into account an exit point from the Site that is unlikely to be blocked by future developments outside of the Site boundary and the presence of residential areas, natural and built linear infrastructure (such as rivers, rail lines and motorways), and designated natural and built heritage sites.

In accordance with the DECC guidance an indicative route corridor of 1 km in width has been assumed up to approximately 10 km. This corresponds to a point on the route that had been proposed for the Yorkshire – Humber CO_2 pipeline. From that point a 10 km corridor to the coast is shown centred on the route of the Yorkshire - Humber pipeline, since this route has previously been evaluated for that project. From an indicative landfall in the vicinity of Barmston on the Yorkshire coast a pipeline route to both identified fields has been identified that avoids the major infrastructure in the North Sea (production platforms and off-shore windfarms).

The economic assessment of the CCS indicates a capital cost of circa £1.2 - 1.6 billion for Eggborough CCGT assuming up to 149 Mt of CO_2 captured with operating and pumping costs of the CCS plant and pipeline estimated to be £57/t. The addition of CCS at the Proposed Development therefore only starts to potentially become economically feasible at a cost of carbon in excess of £57/tonne, assuming that the capital costs can be spread over 35 years of CO_2 capture at high load factors.

Accordingly, deployment of CCS will add significant cost to both the capital outlay and the operation of any power station and currently is not considered to represent the Best Available Technique (BAT) for the Proposed Development.

However, subject to market conditions, based on high level assumptions, the Proposed Development can in principal achieve an economically viable carbon capture solution if required in the future, as the site:

- has sufficient space allocated and reserved for the potential retrofit of CCS if required; and
- has access to potentially secure geological carbon storage facilities that have capacity for the foreseeable future.

Although not currently classed as hazardous, it is recognised that the release of large quantities of CO2 could result in a major accident. The assessment of safety in relation to CCS is therefore focussed on the bulk storage of CO2. No bulk storage of dense or gaseous phase CO2 is proposed in for this Development. The only 'stored' CO2 on site would therefore be the inventory in the capture plant and on-site pipework, and this is envisaged to be considerably less than five tonnes. On this basis in is concluded that CCS in relation to this development is unlikely to pose a major accident risk.

1.0 INTRODUCTION

Overview

1.1 This Carbon Capture Readiness (CCR) assessment has been prepared on behalf of Eggborough Power Limited ('EPL' or the 'Applicant'). It forms part of the application (the 'Application') for a Development Consent Order (a 'DCO'), that has been submitted to the Secretary of State (the 'SoS') for Business, Energy and Industrial Strategy, under section 37 of 'The Planning Act 2008' (the 'PA 2008').

1.2 EPL is seeking development consent for the construction, operation and maintenance of a new gas-fired electricity generating station with a gross output capacity of up to 2,500 megawatts ('MW'), including electrical and water connections, a new gas supply pipeline and other associated development (the 'Project' or 'Proposed Development') on land at and in the vicinity of the existing Eggborough coal-fired power station, near Selby, North Yorkshire.

1.3 A DCO is required for the Proposed Development as it falls within the definition and thresholds for a 'Nationally Significant Infrastructure Project' (a 'NSIP') under sections 14 and 15(2) of the PA 2008.

1.4 The DCO, if made by the SoS, would be known as the 'Eggborough CCGT (Generating Station) Order' (the 'Order').

EPL

1.5 EPL owns and operates the existing Eggborough coal-fired power station (the 'existing coal-fired power station'), near Selby, including a significant proportion of the land required for the Proposed Development.

1.6 EPL was acquired by EP UK Investments Ltd (EP UK) in late 2014; a subsidiary of Energetický A Prumyslový Holding ('EPH'). EPH owns and operates energy generation assets in the Czech Republic, Slovak Republic, Germany, Italy, Hungary, Poland and the United Kingdom.

The Proposed Development Site

1.7 The Proposed Development Site (the 'Site' or the 'Order limits') is located at and in the vicinity of the existing coal-fired power station approximately 8 kilometres south of Selby.

1.8 The existing coal-fired power station is bound to the north by Wand Lane, with the River Aire located approximately 650 metres ('m') further to the north and the A19 Selby Road immediately to the west. Eggborough Village is located approximately 750 m to the south-west.

1.9 The entire Site lies within the administrative boundaries of Selby District Council ('SDC') and North Yorkshire County Council ('NYCC').

1.10 The existing coal-fired power station was officially opened in 1970 and comprises four coal-fired boilers units, which together are capable of generating up to 2,000 MW of electricity. The existing coal-fired power station also includes a turbine hall and boiler house, an emissions stack (chimney) of approximately 198 m in height, eight concrete cooling towers of approximately 115 m in height, an administration and control block, a coal stockyard and a dedicated rail line for the delivery of coal, in addition to ancillary buildings, structures and infrastructure and utility connections.

1.11 The Site itself extends to approximately 102 hectares and comprises land within the operational area of the existing coal-fired power station for the new gas-fired generating station and electrical and groundwater supply connections; corridors of land to the north of the existing coal-fired power station for the cooling water connections and gas supply pipeline; an area of land to the south-east of the main coal stockyard for surface water discharge connections; and corridors of land to the west and south of the operational area of the existing coal-fired power station for ground and towns water supply connections and access.

1.12 The land required for the generating station and electrical and groundwater connections is owned by EPL, as well as the majority of the land for the cooling and towns water and surface water discharge connections. The majority of the land required for the gas supply pipeline is not owned by EPL.

1.13 The area surrounding the Site is predominantly flat and for the most part comprises agricultural land interspersed with small settlements and farmsteads. The area is however crossed by transport infrastructure, notably the A19 and railway lines, including the East Coast Mainline, in addition to overhead electricity lines associated with the existing coal-fired power station and other power stations within the wider area.

1.14 A more detailed description of the Site is provided at Chapter 3 'Description of the Site' of the Environmental Statement ('ES') Volume I (Application Document Ref. 6.2).

The Proposed Development

1.15 The main components of the Proposed Development are summarised below:

- The **'Proposed Power Plant'** (Work No. 1) - an electricity generating station with a gross output capacity of up to 2,500 MW located on the main coal stockyard area of the existing coal-fired power station, comprising:
  - Work No. 1A - a combined cycle gas turbine ('CCGT') plant, comprising up to three CCGT units, including turbine hall and heat recovery steam generator buildings, emissions stacks and administration/control buildings;
  - Work No. 1B - a peaking plant and black start plant fuelled by natural gas with a combined gross output capacity of up to 299 MW, comprising a peaking plant consisting of up to two open cycle gas turbine units or up to ten reciprocating engines and a black start plant consisting of one open cycle gas turbine unit or up to three reciprocating gas engines, including turbine buildings, diesel generators and storage tanks for black start start-up prior to gas-firing and emissions stacks;
  - Work No. 1C - combined cycle gas turbine plant cooling infrastructure, comprising up to three banks of cooling towers, cooling water pump house buildings and cooling water dosing plant buildings; and
  - ancillary buildings, enclosures, plant, equipment and infrastructure connections and works.
- The **'Proposed Electricity Connection'** (Work No. 3) - electrical connection works, comprising:

  - Work No. 3A - up to 400 kilovolt ('kV') underground electrical cables to and from the existing National Grid ('NG') 400 kV substation;
  - Work No. 3B - works within the NG substation, including underground and over electrical cables, connection to busbars and upgraded or replacement equipment.
- The **'Proposed Cooling Water Connections'** (Work No. 4) - cooling water connection works, comprising works to the existing cooling water supply and discharge pipelines and intake and outfall structures within the River Aire, including, as necessary, upgraded or replacement pipelines, buildings, enclosures and structures, and underground electrical supply cables, transformers and control systems cables.
- The **'Proposed Ground and Towns Water Connections'** (Work No. 5) - ground and towns water supply connection works, comprising works to the existing groundwater boreholes and pipelines, existing towns water pipelines, replacement and new pipelines, plant, buildings, enclosures and structures, and underground electrical supply cables, transformers and control systems cables.
- The **'Proposed Access and Rail Works'** (Work No. 10) - rail infrastructure and access works, comprising alterations to or replacement of the existing private rail line serving the existing coal-fired power station site, including new rail lines, installation of replacement crossover points and ancillary equipment and vehicular and pedestrian access and facilities.
- The **'Proposed Surface Water Discharge Connection'** (Work No. 9) - surface water drainage connection works to Hensall Dyke to the south-east of the main coal stockyard, comprising works to install or upgrade drainage pipes and works to Hensall Dyke.
- The **'Proposed Gas Connection'** (Work No. 6) - gas supply pipeline connection works for the transport of natural gas to Work No. 1, comprising an underground high pressure steel pipeline of up to 1,000 millimetres (nominal bore) in diameter and approximately 4.6 kilometres in length, including cathodic protection posts, marker posts and underground electrical supply cables, transformers and control systems cables, running from Work No. 1 under the River Aire to a connection point with the National Transmission System ('NTS') for gas No. 29 Feeder pipeline west of Burn Village.
- The **'Proposed AGI'** (Work No. 7) - an Above Ground Installation ('AGI') west of Burn Village, connecting the gas supply pipeline (Work No. 6) to the NTS No. 29 Feeder pipeline, comprising:
  - Work No. 7A - a compound for National Grid's apparatus; and
  - Work No. 7B - a compound for EPL's apparatus.
- The **'Proposed Construction Laydown Area'** (Work No. 2A) - an area for temporary construction and laydown during the construction phase, including contractor compounds and facilities.
- The **'Proposed Carbon Capture Readiness ('CCR') Land'** (Work No. 2B) - an area of land to be reserved for carbon capture plant should such technology become viable in the future. It is proposed that this 'reserve' land is provided on part of the area to be used for temporary construction and laydown.
- The **'Proposed Retained Landscaping'** (Work No. 8) - encompassing the existing mature tree and shrub planting along the northern side of Wand Lane and to the eastern boundary of the existing coal-fired power station site, including that on the embankment around the eastern, southern and western boundaries of the main coal stockyard.

1.16 The 'associated development', for the purposes of section 115 of the PA 2008 comprises Work Nos. 2 to 10 of the Proposed Development.

1.17 It is anticipated that subject to the DCO having been made by the SoS (and a final investment decision by EPL), construction work on the Proposed Development would commence in early 2019. The overall construction programme is expected to last approximately three years, although the duration of the electrical and water connection and gas supply pipeline connection works would be significantly less. The construction phase is therefore anticipated to be completed in 2022 with the Proposed Development entering commercial operation later that year.

1.18 A more detailed description of the Proposed Development is provided at Schedule 1 'Authorised Development' of the draft DCO and Chapter 4 'The Proposed Development' of the ES Volume I (Application Document Ref. 6.2) and the areas within which each of the main components of the Proposed Development are to be built is shown by the coloured and hatched areas on the Works Plans (Application Document Ref. 4.4).

The Purpose and Structure of this Document

1.19 The purpose of this report is to demonstrate that, amongst other matters (see below), it would remain technically feasible to retrofit Carbon Capture technology in the future to the Proposed Development. CCR needs to be demonstrable for all new combustion generating stations with a generating capacity at or over 300 MW (and of a type covered by the European Union Large Combustion Plant Directive) as set out in Section 4.7 of the Overarching National Policy Statement for Energy[1], the Carbon Capture and Storage (CCS) Directive[2] and also the Industrial Emissions Directive (IED)[3].

1.20 This document has been produced in accordance with the requirements of the Department of Energy and Climate Change (DECC) November 2009 carbon capture guidance "Carbon Capture Readiness (CCR) – A Guidance Note for Section 36 Electricity Act 1989 consent applications".[4]

1.21 The following approach has been used for this CCR assessment:

- based on a high level conceptual design for the Proposed Development, a preferred carbon capture technology was identified for potential future retrofit, based on thermal and process modelling, and current CCS technology availability;
- the sizing and utility demand of the main CCS equipment that would be required was established using thermal and process modelling. Site layouts were prepared to show that the equipment would fit into the land currently identified to be retained for CCR purposes;
- geological storage sites with storage capacities capable of accepting the carbon output from the Proposed Development over its design life were identified, utilising a DTI study[5];

[1] Department of Energy and Climate Change (DECC) (July 2011) Overarching National Policy Statement (NPS) for Energy: EN-1
[2] Directive on the Geological Storage of Carbon Dioxide (Directive 2009/31/EC), Article 33
[3] Directive on Industrial Emissions (Integrated Pollution Prevention and Control) (Directive 2010/75/EU), Article 36
[4] It should be noted that the NPS EN-1 directs that should this CCR guidance should be followed and references in the guidance to Section 36 consents should be taken to include references to development consent orders under the Planning Act 2008 as appropriate.
[5] Industrial Carbon Dioxide Emissions and Carbon Dioxide Storage Potential in the UK, 2006

- potential routes to transport the captured carbon dioxide (CO_2) from the Proposed Development site to the potential geological storage sites were identified;
- an economic assessment that encompasses retrofitting carbon capture technology, transport and storage of CO_2 was carried out for the CCS plant to estimate the price of EU allowances for CO_2 which are necessary to make the Proposed Development feasible with CCS; and
- a high level assessment of the Health and Safety issues associated with the CCS plant was undertaken.

1.22 Based on the CCR guidance detailed in Section 2, this report is structured as follows:

- **Section 1:** Introduction;
- **Section 2:** Legislative Background;
- **Section 3:** Proposed Development;
- **Sections 4, 5, 6, 7 and 8:** Technical and Economic Feasibility Assessments for chosen technology, storage and transport; and
- **Section 9:** Health and Safety Assessment.

2.0 LEGISLATIVE BACKGROUND

EU Directive on Geological Storage of Carbon Dioxide

2.1 The European Union (EU) published the Directive on the Geological Storage of Carbon Dioxide (Directive 2009/31/EC) ("the Directive") in the Official Journal of the European Union on 5 June 2009, with the Directive coming into force on 25 June 2009.

2.2 Article 33 of the Directive requires an amendment to Directive 2001/80/EC (commonly known as the Large Combustion Plants Directive) such that developers of all combustion plants with an electrical capacity of 300 MW or more (and for which the construction / operating license was granted after the date of the Directive) are required to carry out a study to assess:

- whether suitable storage sites for CO_2 are available;
- whether transport facilities to transport CO_2 are technically and economically feasible; and
- whether it is technically and economically feasible to retrofit for the capture of CO_2 emitted from the power station.

This is known as a 'CCR Feasibility Study'.

2.3 Article 36 of the IED (which also originates from Article 33 of Directive 2009/31/EC on the Geological Storage of Carbon dioxide) also requires new large combustion plant to be CCR.

The Carbon Capture Readiness (Electricity Generating Stations) Regulations 2013

2.4 The Carbon Capture Readiness (Electricity Generating Stations) Regulations 2013 (the CCR Regulations) came into force on 25 November 2013. These regulations transpose Article 36 of the IED into UK law.

2.5 The CCR Regulations provide that no order for development consent (in England and Wales) may be made in relation to a combustion plant with a capacity at or over 300 MWe unless the relevant authority has determined (on the basis of an assessment carried out by the applicant) whether it is technically and economically feasible to retrofit the equipment necessary to capture the carbon dioxide that would otherwise be emitted from the plant, and to transport and store such carbon dioxide from the site.

2.6 The CCR Regulations summarise the need for a CCR Feasibility Study and state (at Regulation 2(1)) that a: *"CCR assessment", in relation to a combustion plant, means an assessment as to whether the CCR conditions are met in relation to that plant"*.

2.7 In terms of the "CCR conditions", CCR Regulation 2(2) states that:

"for the purposes of these Regulations, the CCR conditions are met in relation to a combustion plant, if, in respect of all of its expected emissions of CO2 –

- *Suitable storage sites are available;*
- *It is technically and economically feasible to retrofit the plant with the equipment necessary to capture that CO2; and*
- *It is technically and economically feasible to transport such captured CO2 to the storage sites referred to in sub-paragraph (a)".*

2.8 Furthermore, CCR Regulation 3(1) states that:

"The Secretary of State must not make a relevant consent order unless the Secretary of State has determined whether the CCR conditions are met in relation to the combustion plant to which the consent order relates".

2.9 CCR Regulation 3(3) states that:

"If the Secretary of State –

a) determines that the CCR conditions are met in relation to a combustion plant; and

b) decides to make a relevant consent order in respect of that plant,

the Secretary of State must include a requirement in the relevant consent order that suitable space is set aside for the equipment necessary to capture and compress all of the CO_2 that would otherwise be emitted from the plant".

Planning Policy

2.10 The Proposed Development falls under Sections 14(1)(a) and 15 of the Planning Act 2008 and is therefore a NSIP. Under Section 104(3) of the Planning Act 2008, applications for NSIPs must be determined by the Secretary of State in accordance with policy set out in the relevant National Policy Statements (NPS) (where relevant NPS have been designated, as here), except to the extent that the matters set out in the remainder of section 104 apply.

2.11 As noted above the Overarching National Policy Statement For Energy has been designated and therefore applies to the determination of the Application, pursuant to section 104. In relation to CCR, the Overarching National Policy Statement For Energy states:

"all applications for new combustion plant which are of generating capacity at or over 300MW and of a type covered by the EU's Large Combustion Plant Directive (LCPD) should demonstrate that the plant is 'Carbon Capture Ready' (CCR) before consent may be given".

Department of Energy and Climate Change Guidance on Carbon Capture Readiness

2.12 The Department of Energy and Climate Change (DECC) published guidance on CCR in November 2009[6]. Although the guidance was drafted in respect of Section 36 Applications under the Electricity Act 1989; the text of the guidance makes it explicit that it applies to the applications to the Planning Inspectorate for generating stations of 50 MW or more, under the Planning Act 2008. This is also confirmed by the Overarching National Policy Statement For Energy.

2.13 The guidance makes it clear that, under the Government's CCR Policy, as part of their consent order application, applicants are required to:

- demonstrate that sufficient space is available on or near the site to accommodate carbon capture and storage (CCS) equipment in the future;

[6] Department of Energy and Climate Change (DECC) (November 2009) 'Carbon Capture Readiness (CCR) – A Guidance Note for Section 36 Electricity Act 1989 consent applications'

- undertake an assessment into the technical feasibility of retrofitting CCS equipment;
- propose a suitable area of deep geological storage offshore for the storage of captured CO_2;
- undertake an assessment into the technical feasibility of transporting the captured CO_2 to their proposed storage area;
- assess the likelihood that it will be economically feasible within the power station's lifetime to link it to a full CCS chain, covering retrofitting of capture equipment, transport and storage; and
- if necessary, apply for and obtain Hazardous Substance Consent (HSC) when applying for consent.

2.1 This CCR report has therefore been prepared to fulfil the requirements of the DECC November 2009 guidance as set out below:

- Technical Assessment of Sufficient Space for CCS Equipment: An assessment of appropriate space set aside to accommodate future carbon capture equipment is provided in **Section 4** of this report.
- Technical Assessment of Feasibility of CCS Retrofit: Annex C of the Guidance provides a detailed advisory checklist of the information to be included in a CCR Feasibility Study report on the technical assessment of the feasibility of retrofitting CCS equipment for a New Natural Gas Combined Cycle Power Station using Post-Combustion Solvent Scrubbing. **Section 5** of this report deals with the technical response to these requirements for the Proposed Development.
- Technical Feasibility of Storage of Captured CO_2: In accordance with the guidance, at least two fields or aquifers with an appropriate CO_2 storage capacity, which have been listed in either the "valid" or "realistic" categories in the DTI's 2006 study 'Industrial Carbon Dioxide Emissions and Carbon Dioxide Storage Potential in the UK', should be proposed as suitable CO_2 storage locations for the Development. Such sites are identified in **Section 6** of this report.
- Technical Feasibility of Transport of Captured CO_2: The Guidance states that the feasibility of any proposed site for a new combustion station will be influenced by the availability of transport routes to the proposed storage area. The technical feasibility of transporting the captured CO_2 to the storage area proposed for the Proposed Development is assessed in **Section 7** of this report.
- Economic Assessment of the Feasibility of CCS: The Guidance states that the main aim of the economic assessment is to provide an indication of the future likelihood of a retrofit of CCS equipment, CO_2 transport and storage of CO_2 being economically feasible at some stage during the proposed plant's operational lifetime. This is developed in **Section 8** of this report.
- Health and Safety Analysis: An analysis of Health and Safety issues associated with the CCS plant including consideration of whether a Hazardous Substances Consent may be required for the CCS plant proposed for the Proposed Development is provided in **Section 9** of this report.

3.0 DESCRIPTION OF THE PROPOSED DEVELOPMENT

3.1 The Site has been selected by the Applicant for the development of a CCGT generating station, as opposed to other potentially available sites for the following reasons:

- the Site has a long history of power generation;
- the existing coal-fired power station is facing closure and future redevelopment of the Power Station site would create similar employment opportunities (albeit a smaller number of operational staff will be required compared to the existing coal-fired power station);
- the Site has excellent grid, water and transport links and is a brownfield site which is considered more attractive to redevelop for large scale power generation than a greenfield one;
- the majority of the Site is largely in the freehold ownership of the Applicant; and
- the Proposed Power Plant Site is located relatively close to the National Grid gas transmission network (Feeder 29 is located approximately 3.1 km to the north of the existing coal-fired power station site).

3.2 As there are multiple components which together make up the Site, for ease of reference, the different areas of the Site are described as follows:

- Proposed Power Plant Site - the CCGT, peaking plant, black start facility and associated infrastructure within the existing coal stockyard area, and a small area to the north-east of the coal stockyard area;
- Proposed Cooling Water Connections - from the Proposed Power Plant Site to the existing abstraction point located upstream of the weir at Chapel Haddlesey (non tidal) and to the existing outfall point located within the tidal section of the River at a meander known as Eggborough Ings;
- Proposed Borehole and Towns Main Water Connections - there are two existing groundwater abstraction boreholes that are proposed to be used, one adjacent to the Eggborough Sports and Leisure Complex and one further south near the A19/ A645 Weeland Road roundabout, which would require new connections to the Proposed Development (although these would be partly along the routes of the existing pipelines to the existing coal-fired power station) (note that a towns main water connection (re-routed from the existing coal-fired power station's towns main water supply) is also proposed as back up in the event of failure of supply from the Proposed Borehole Water Connection, and this will be routed along the access road from Hensall Gate to the Proposed Power Plant Site);
- Proposed Surface Water Discharge Connection – for the discharge of surface water to Hensall Dyke in the south-east of the Site;
- Proposed Electricity Connection - from the Proposed Power Plant Site to the existing National Grid sub station within the existing coal-fired power station site;
- Proposed Gas Connection and AGI - from the Proposed Power Plant Site to Feeder 29, the National Grid Transmission network, to the north of the Site at a point south-west of Burn village;

- Proposed Rail and Access Works – an area to the west of the Proposed Power Plant Site which is predominantly to be used for access via the existing Tranmore Lane access and potential works to alter the existing rail infrastructure for use during construction;
- Proposed Construction Laydown area – within part of the existing coal-fired power station site;
- Proposed CCR Land - land is required to be set aside for a potential future carbon capture plant, as per Section 4.7 of the Overarching National Policy Statement (NPS) (EN-1) (Department of Energy and Climate Change, 2011). This is located within the Proposed Construction Laydown area and within the existing coal-fired power station site; and
- Retained Landscaping areas – areas of existing plantation woodland that are to be retained for landscape and biodiversity benefit.

Plant Description

3.3 The Proposed Development comprises the construction and operation of a CCGT power station with a gross output capacity of up to 2,500 MW, comprising up to three high efficiency combined cycle gas turbines and associated steam turbines, plus a peaking plant (either up to two 'fast response' open cycle gas turbines (OCGT) or up to 10 reciprocating gas engines), with black start capability.

3.4 The exact capacity of the proposed CCGT units is not yet fixed, as it will depend on the commercial decision as to which technology provider is contracted to design and build the plant. However, the gross output capacity of the peaking plant is restricted to a maximum of 299 MW.

3.5 As stated in the DECC CCR Guidance, the CCR requirements (and therefore that guidance) apply to applications for power stations with an electrical generating capacity at or over 300 MW and of a type covered by the EU Large Combustion Plant Directive (LCPD) [now the IED]. The Guidance states *"This capacity threshold for CCR is based on the capacity of the new power station as a whole, rather than on the individual capacity of each of the units which make up the power station. However, where an application for a variety of generating unit types is received (for example combined cycle and open cycle gas turbines), the threshold is applied to the new units of the same type on the site."* (DECC, 2009, emphasis added).

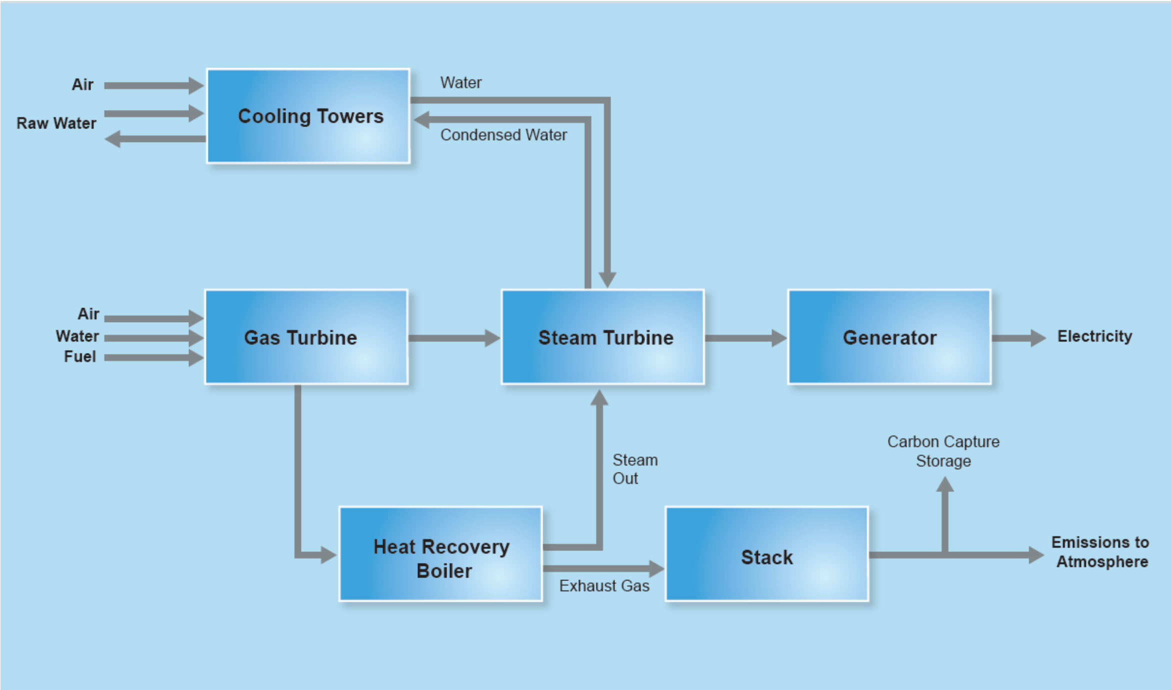
3.6 By restricting the output capacity of the peaking plant (a different type of unit to the CCGT) to 299 MW or less, therefore, the CCR requirements do not apply to any peaking plant or black start facility sought as part of the Proposed Development. For the purposes this assessment, the maximum potential generation capacity of 2,500 MW has therefore been assumed to be supplied entirely by CCGT generation, since this would represent the largest potential plant capacity to which the CCR requirements could apply, and therefore represents the most conservative scenario for space allocation to meet CCR requirements.

3.7 In a CCGT power station, natural gas fuel is fired in the combustion system to drive a gas turbine, which is connected to a generator producing electricity. An amount of heat remains in the gas turbine exhaust, and this is passed into a Heat Recovery Steam Generator (HRSG), a type of boiler, to make steam to generate additional electricity via a steam turbine. The exhaust steam from the steam turbine is condensed back into water, which is returned to the HRSG to continue the process. The waste gases from the heat recovery boiler will be released into the atmosphere via an exhaust stack, following appropriate treatment, with an option to divert this flow to a future carbon capture plant.

3.8 A schematic of the power generation process associated with the Proposed Development is provided below in Plate 1.

3.9 The electrical efficiency of a modern CCGT power station is greater than 60%, which is considerably higher than that for a conventional coal, biomass or oil-fired generating plant.

Plate 1: Power Generation Process (for a single shaft plant configuration)

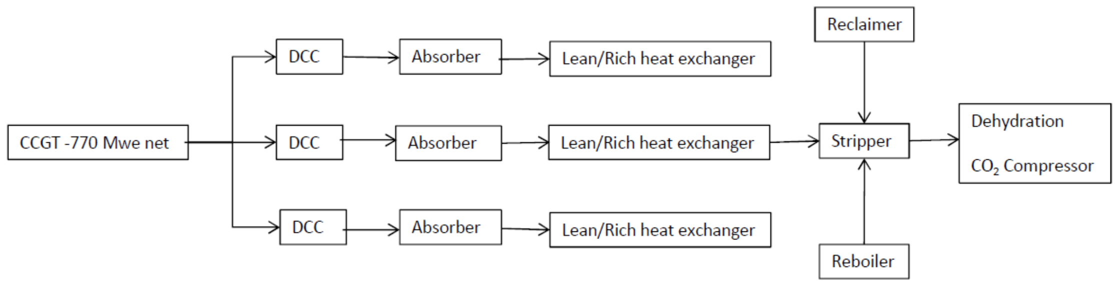


3.10 As outlined previously, while the final design of the plant has not been made, for the purposes of this assessment a configuration of 3 single shaft CCGT H Class units up to a maximum of 2,500 MW has been assumed. Based on initial discussions with equipment manufacturers, the largest capacity H Class units currently available are the GE 9HA.02 units, and these have been used in this assessment to provide the indicative exhaust gas data to allow the relevant space calculations to be undertaken.

3.11 There are three potential options for carbon capture technology that could be installed on a generating station – post combustion carbon capture, pre-combustion carbon capture and oxy-firing. These are discussed further below. However, it is considered that the most cost effective approach to retrofitting carbon capture technology to an existing generating station is the addition of post combustion carbon capture equipment, since the other technologies require extensive redesign of the generating plant itself and therefore need to be installed from the outset, rather than as a retrofit application. For this reason, use of post combustion carbon capture technology is assumed for the remainder of this report.

3.12 A schematic of the potential post combustion carbon capture process associated with the Proposed Development is provided in Plate 2. Three separate CCS trains are considered to be appropriate for a three unit H-Class CCGT configuration, due to the volume of CO_2 generated, with one train dedicated to each CCGT unit.

Plate 2: General Process Block Diagram



3.13 Table 3.1 presents performance data of the Proposed Development based on the largest currently available H Class unit as outlined above, with emissions data increased pro rata to reach a theoretical plant export limit of 2,500 MW to present the worst case capture requirement. The performance data is estimated at ISO conditions (60% of relative humidity and 15.5°C) and 45 mbar of vacuum pressure in the condenser of the CCGT. A typical National Grid natural gas composition has been used for estimating the performance of the development.

Table 3.1: Performance data

Parameter	CCGT
Net Power Export Capacity MW	2,500
Net heat rate MJ / MWh	6180

Flue Gas Composition and Conditions

3.14 Details regarding the CCS plant feed gas composition and flow rate were provided from initial engineering design calculations for the Proposed Development. The information provided is for the flue gas after the heat recovery steam generator (HRSG), which is proposed to be directed to the carbon capture plant once that is installed (see Table 3.2).

Table 3.2: Gas Turbine Exhaust Gas

Parameter	CCGT
Exhaust gas mass flow per stack (kg/s)	3,738
Stack exhaust gas temperature °C	75
Composition (mole %)	
N_2	75.16
O_2	11.79

Parameter	CCGT
CO_2	4.16
H_2O	8.89

Proposed Carbon Capture and Storage Technology

3.15 The current regulatory position is that the carbon capture plant would not be installed until CO_2 capture is either mandated or economically and technically viable. The current Emissions Performance Standard (EPS) set by the UK Government for new power generating stations is set at a level (450 g CO_2/kWh) that would not require CCS to be installed on new build gas-fired power stations. This level is proposed by UK Government to be maintained for consented plants until 2045.

3.16 As outlined previously, there are three alternative carbon capture technologies available, namely:

- pre-combustion carbon capture;
- post combustion carbon capture; and
- oxy-combustion carbon capture.

3.17 Although at the time of eventual installation, it is possible that the number of potential technologies will have increased, this CCR feasibility assessment focuses solely on the technology that is the most developed and closest to commercial deployment at present, as required by the DECC guidance.

3.18 As any CCS would have to be retrofitted to the CCGT plant at some point in the future after several years of operation, this CCR assessment has focussed on the potential use of post combustion carbon capture, as this would be the most suitable of the three potential CCS technologies for retrofitting to an existing operational CCGT.

3.19 The feasibility of CCS for the Proposed Development has therefore been assessed on the basis of the best currently available post combustion carbon capture technology which, for carbon capture from combustion flue gases, is using amine based solution.

3.20 Further justification as to the choice of CCS technology considered most appropriate for the Proposed Development is provided in **Appendix 1**.

Process Design Basis

3.21 The conceptual design of the carbon capture system proposed for the Proposed Development has been based on the ISO reference conditions, *i.e.* 60% relative humidity and 15.5°C. The following information has also been assumed:

Treated Flue Gas

- design CO_2 Recovery Rate: 90%; and

- amine based solution content within the discharged flue gas: Less than 3 ppmv (At any detailed design phase, the need for a lower amine solution concentration within the flue gas would be evaluated when considering potential odour impacts).

CO_2 for Sequestration

- volume: 5.75 million tonnes per annum (mtpa) based on 90% capture efficiency and assuming the CCGT will be in operation 7884 hrs per year (90% load factor) as a worst case;
- pressure: >150 bar supply pressure;
- temperature: Cool to 35 – 40 °C to enter pipeline, and gas must be dehydrated to prevent corrosion of the steel pipe and hydrates formation;
- offshore CO_2 Pipeline length: ~250-350 km depending on selected storage location; and
- CO_2 Pipeline diameter: 35-65 cm.

Space left available on site for carbon capture plant to be installed

- total: 120,000 m^2 of the overall Site. This is based on the DECC Guidance[7] space requirement modified by the Imperial College paper[8] which indicates that a space requirement of 48 m^2/MW installed capacity is sufficient for carbon capture without detailed design layouts being required.

Post Combustion Amine Scrubbing

3.22 As discussed, the feasibility of CCS for the Proposed Development has been assessed on the basis of post combustion amine based absorption. The post-combustion amine scrubbing carbon capture process consists of the following main process stages:

- flue gas cooling;
- CO_2 absorption;
- CO_2 stripping;
- flue gas discharge;
- CO_2 discharge; and
- CO_2 compression.

A simplified process flow diagram is presented in **Plate 3**.

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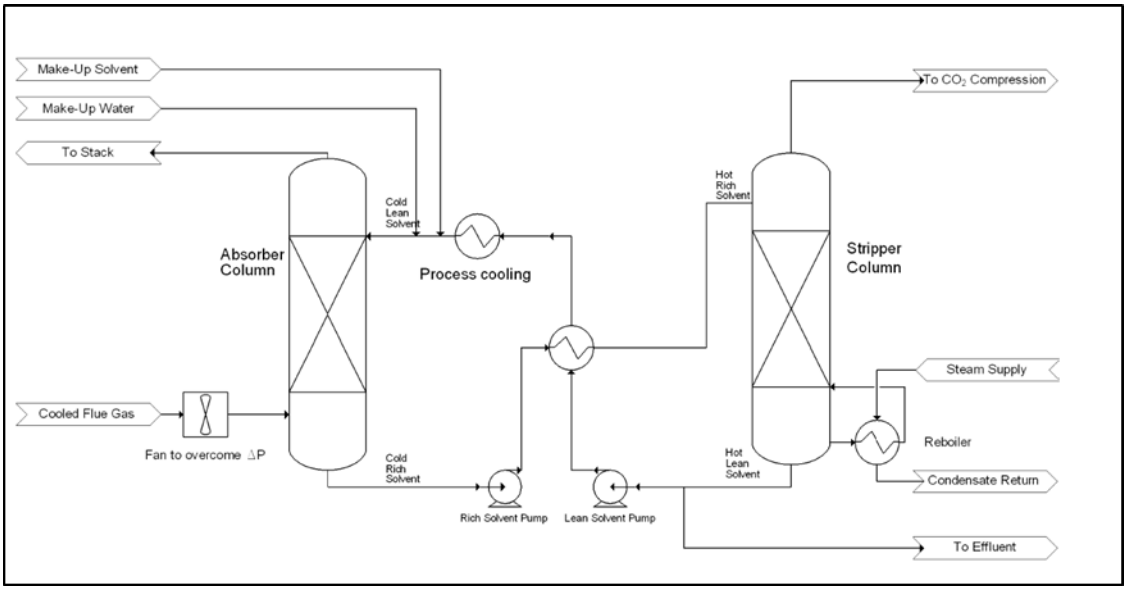
[7] Carbon Capture Readiness (CCR) A guidance note for Section 36 Electricity Act 1989 consent applications – Department for Energy and Climate Change, November 2009

[8] Assessment of the validity of "Approximate minimum land footprint for some types of CO2 capture plant" provided as a guide to the Environment Agency assessment of Carbon Capture Readiness in DECC's CCR Guide for Applications under Section 36 of the Electricity Act 1989, Imperial College, 2010

Plate 3: Post Combustion Amine Scrubbing Carbon Capture Process

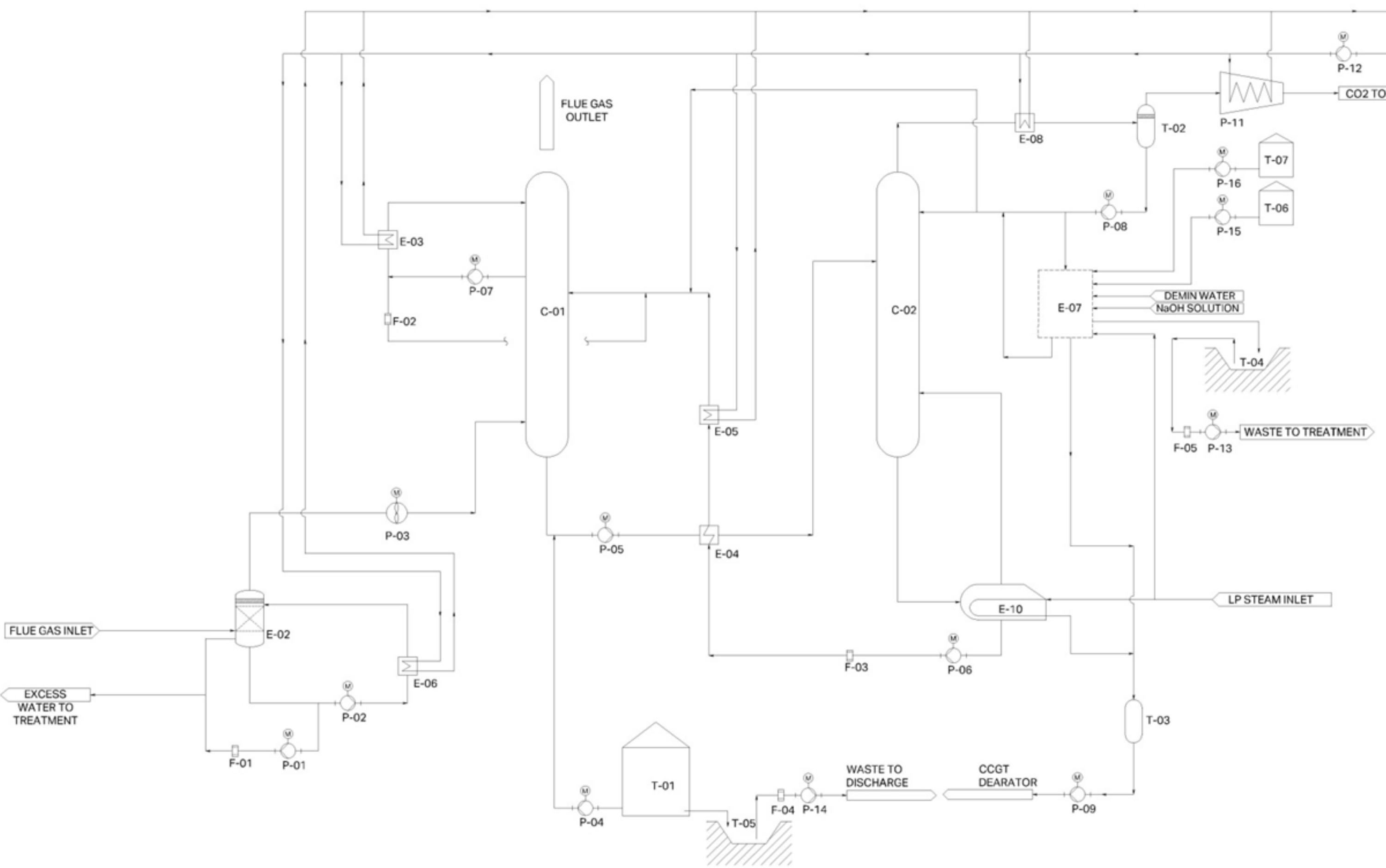


3.23 In order to enhance the chemical CO_2 absorption process, the flue gas is cooled down to around 45 – 55 °C. Options for flue gas cooling include gas-gas re-heaters and/or direct contact cooling (quenching) with water. After the cooling process, the flue gas is blown through an absorber column where it comes into contact with the liquid amine based solvent. Around 90% of the CO_2 in the flue gas is chemically absorbed through acid-base neutralization reactions with the amine. This creates a CO_2 rich stream of liquid solvent. The CO_2 rich solvent is pumped out of the absorber column and is heated in the cross lean to rich solvent heat exchanger before entry into a stripper column.

3.24 In the stripper column the solvent is heated further by the condensation of steam in the reboiler. The amine can absorb less CO_2 at higher temperatures, so heating the solvent releases the CO_2 as a gas. The lean liquid solvent is pumped from the bottom of the stripper, cooled in the heat exchanger, and further cooled before re-entry to the absorber. The CO_2 gas, containing a large quantity of steam, exits at the top of the stripper. It is cooled to remove the steam and compressed or liquefied for transport. Condensed steam and amine solvent removed from the CO_2 stream are returned to the capture plant for re-use. Amine absorption plants can typically capture approximately 90% of the CO_2 in a flue gas stream and can result in an end CO_2 purity of over 99%.

3.25 The exhaust flow from the 'H Class' Gas Turbine (GT) modelled as part of this assessment would require the absorption of 15,750 tonnes per day (tpd) of CO_2 at 90% load. Consequently, a layout with one absorber train per CCGT train is anticipated. Each absorption train requires a Direct Contact Cooler (DCC), blower, absorber and associated filters, heat exchangers and pumps. There can be several absorptions trains all linked to a single regeneration and CO_2 compression section. A block diagram schematic showing the suggested configuration of the CCS system is provided in Plate 4. In this diagram the three CCS trains are sized to match the capacity of each CCGT trains. This flue gas system shall include a bypass system of the flue gases directly to the main stack by means of bypass and isolation dampers in case the CCS plant is unavailable.

Plate 4: Process flow diagram for an amine absorber train



	EQUIPMENT LIST
EQUIP. No.	DESCRIPTION
P-01	DCC FILTER PUMP
P-02	DCC CIRCULATING WATER PUMP
P-03	FLUE GAS BLOWER
P-04	SOLVENT MAKE UP PUMP
P-05	RICH SOLVENT PUMP
P-06	LEAN SOLVENT PUMP
P-07	WASH WATER COOLER PUMP
P-08	REFLUX PUMP
P-09	CONDENSATE to CCGT PUMP
P-10	CONDENSATE TO CHP PUMP
P-11	CO2 MULTISTAGE COMPRESSOR
P-12	HCT RECIRCULATION PUMP
P-13	WASTE WATER SUMP PUMP
P-14	SOLVENT SUMP PUMP
P-15	H2S04 SOLUTION PUMP
P-16	NaOH SOLUTION PUMP
E-02	DIRECT CONTACT COOLER
E-03	WATER WASH COOLER
E-04	SOLVENT CROSS HE
E-05	LEAN SOLVENT COOLER
E-06	DCC WATER COOLER
E-07	RECLAIMER
E-08	STRIPPER CONDENSER
E-09	FIN FAN COOLERS
E-10	REBOILER
T-01	MEA SOLVENT STORAGE TANK
T-02	OVERHEAD ACCUMULATOR
T-03	STEAM CONDENSATE DRUM
T-04	WASTE WATER SUMP
T-05	SOLVENT SUMP
T-06	H2S04 SOLUTION TANK
T-07	NaOH SOLUTION TANK
C-01	ABSORBER
C-02	STRIPPER
F-01	DCC CIRCULATING WATER FILTER
F-02	WASH WATER FILTER
F-03	LEAN SOLVENT FILTER
F-04	SOLVENT SUMP FILTER
F-05	WASTE WATER SUMP FILTER

4.0 TECHNICAL ASSESSMENT: SPACE ON SITE

4.1 As shown in Plate 5, the space available for the carbon capture plant at Eggborough comprises an area of approximately 120,000 m^2. No off site space would need to be used for the carbon capture plant, except as a temporary construction laydown area. There is significant additional land within the wider Eggborough coal-fired power station site and surrounding the site that is in the ownership of the Applicant and which could be used to provide temporary laydown areas as and when required.

Footprint Estimate

4.2 At this stage, no detailed design of any potential CCS Plant has been undertaken and none would be undertaken until CCS was mandated to be required for the Site. Therefore, for the purposes of this CCR feasibility report a 'worst case' footprint area has been estimated using the following sources of information:

- DECC CCR Guidance;
- Imperial College Paper on CCS Footprint Review;
- AECOM databases on CCS plant design from other CCGT retrofit concept projects;

4.3 On this basis the indicative footprint has been estimated based on the calculations and the list of major equipment presented in Table 4.1. A conservative design margin is applied to allow for ductwork, piping, access and maintenance.

4.4 An indicative 'worst case' total footprint of the CCS plant has been calculated from design principles at approximately 90,000 m^2 (30,000 m^2 per CCS train) *i.e.* well within the space available and to be retained on Site (120,000 m^2) in order to meet the CCR Guidance and Imperial College estimates.

Table 4.1: Worst Case Footprint Estimate (3 trains) Principal Component List

Equipment	Number of Pieces	Length / m	Width / m	Footprint Area / m^2
DCC Filter Pump	6	1.5	1.5	13.5
DCC Circulating Water Pump	6	2.2	2.2	29.0
Blower	3	17	12	612
Solvent Make-up Pump	6	1	1	6
Rich Solvent Pump	6	3.5	2.5	52.5
Lean Solvent Pump	6	3.5	2.5	52.5
Wash Water Circulating Pump	6	1.5	1.5	13.5
Reflux Pump	6	1.5	1.5	13.5
Condensate to Deaerator Pump	6	2	2	24
HCT Recirculation Pump	6	2	2	24
Waste Water Sump Pump	6	1	1	6
Solvent Sump Pump	6	1.5	1.5	13.5

Equipment	Number of Pieces	Length / m	Width / m	Footprint Area / m^2
H_2SO_4 Solution Pump	6	1.5	1.5	13.5
NaOH Solution Pump	6	1.5	1.5	13.5
DCC column	3	10		235.6
Wash Water Cooler	6	2.5	1.5	22.5
Solvent Cross Exchanger	3	72.3	1.7	377.9
Lean Amine Cooler	3	12.6	3.9	145.9
DCC Water Cooler	3	8	3.5	84
Reclaimer	1	14	8.5	119
Stripper Condenser	1	14	2.8	39.2
Hybrid coolers		100	40	4000
Re-boiler	1	16	11	176
Amine Storage Tank		5.5		23.8
Overhead Accumulator	1	4.2		13.9
H_2SO_4 Solution Tank	1	2.8	2.8	7.84
NaOH Solution Tank	1	2.8	2.8	7.84
Absorber	3	10		235.6
Stripper	1	10		78.5
DCC Circulating Water Filter	3	0.5	0.5	0.75
Wash Water Filter	3	0.5	0.5	0.75
Lean Solvent Filter	3	7	4.2	88.2
Solvent Sump Filter	3	0.5	0.5	0.75
Waste Water Sump Filter	3	0.5	0.5	0.75
Activated Carbon Filter	3	4.5	4.5	60.75
Compressor Stage 1 Intercooler	1	8	2	16
Compressor Stage 2 Intercooler	1	8	2	16
Compressor Stage 3 Intercooler	1	8	2	16
Compressor Stage 4 Intercooler	1	8	2	16
Compressor Stage 5 Intercooler	1	8	2	16
Compressor Stage 1 Drum	1	2		3.1
Compressor Stage 2 Drum	1	1		0.8
Compressor Stage 3 Drum	1	0.7		0.4
Compressor Stage 4 Drum	1	0.5		0.2
Compressor Stage 5 Drum	1	0.3		0.1
CO_2 Compression Unit	1	11	7	77
CO_2 Dehydration Unit	1	10	20	200

Equipment	Number of Pieces	Length / m	Width / m	Footprint Area / m^2
Antifoam System	1	6	6	36
Instrument Air System	1	8	8	64
Nitrogen Blanketing System	1	5	5	25
	Total per CCGT Unit			**7093**
	Total per CCGT including margin for ductwork, piping, access etc.			**30,000**
	Total for 3 CCGTs			**90,000**
	CO_2 capture footprint m^2/MW (calculated)			**36**
	CO_2 capture footprint m^2/MW based on Imperial College report			**48**
	CO_2 capture footprint required for 2,500 MW (based on Imperial College report)			**120,000**
	Space retained on site for CCR			**120,000**

Footprint Comparison

4.5 Table 1 in the 2009 CCR Guidance provides an indicative CCR space requirement based on a 500 MW (net) power plant. For a CCGT power plant with post-combustion carbon capture, the indicative CCR space requirement was initially provided at 3.75 ha for 500 MW, which equates to75 m^2/MW.

4.6 However, following the publication of the CCR Guidance, the indicative CCR space requirement was reviewed by Imperial College, London. The Imperial College review concluded that the footprint estimates presented in the 2009 CCR Guidance were overly conservative and recommended the reduction of the indicative CCR space requirement for a CCGT power plant with post-combustion capture by 36%. Therefore, the corrected indicative CCR space requirement is 2.4 ha for 500 MW. This equates to 48 m^2/MW.

4.7 In addition, the review by Imperial College further detailed additional scope for a reduction in the indicative CCS space requirement by 50% to 1.875 ha (including the reduction of 36%) considering technology advances and layout optimisation. This equates to 36 m^2/MW. However, the paper also states that such a reduction can only be justified on the basis of a detailed engineering design (which is not a requirement for a DCO) rather than only a linear scaling of this value.

4.8 For the purposes of this report, while a footprint requirement of circa 90,000 m^2 (36 m^2/MW) has been calculated from the indicative CCS plant component design shown in Table 4-1, a more conservative footprint of 120,000m^2 (48 m^2/MW) has been assumed for CCR purposes for the Proposed Development.

4.9 The space allocation reserved for CCR purposes is therefore sufficient to meet required levels for the Proposed Development, based on DECC and Imperial College requirements.

5.0 TECHNICAL ASSESSMENT – RETROFITTING CARBON CAPTURE TECHNOLOGY

5.1 To demonstrate that the Proposed Development has been designed so that it would be technically feasible to subsequently retrofit carbon capture equipment in the future to the entire capacity of the proposed CCGT generating station, the plant design has been assessed against the criteria presented in Annex C of the DECC CCR guidance note.

C1 Design, Planning Permissions and Approvals

5.2 The feasibility of CCS for the Proposed Development has been assessed on the basis of the best currently available technology, which for post combustion carbon capture from flue gases is capture using amine based absorption. An outline level plot plant for the plant is provided in Figure 1.

C2 Power Plant Location

5.3 It is anticipated that the exit point for the captured CO_2 from the plant will be located at the northern boundary of the Proposed CCR Land as shown on Figure 1 and 2. The final location will be selected depending on the agreed method and route of CO_2 transportation.

5.4 Where appropriate, piperacks will be used to transfer the compressed and dehydrated CO_2 to the defined exit point. This is achievable as the pipe will have an internal diameter of circa 0.65 m assuming an allowable velocity of 3.5 m/s, due to the dense phase of the CO_2.

5.5 Further information on the transport and storage of captured CO_2 off-site is provided in Sections 6 and 7.

C3 Space Requirements

5.6 The total footprint of the carbon capture plant has been calculated and is presented in Section 4. This footprint has been derived from the footprint of each piece of equipment, allowing spacing for piping and maintenance etc. Equipment sizing has been scaled off previous projects involving amine based systems and gas flow design information.

5.7 The footprint was used to prepare the plot plan presented in Figure 1 that demonstrates that space has been allocated for the following:

- CO_2 capture equipment, including any flue gas pre-treatment, and CO_2 drying and compression;
- space for routing flue gas duct to the CO_2 capture equipment;
- steam turbine island additions and modifications;
- any extensions or additions to the balance of plant on the CCGT units where necessary to cater for the additional requirements of the capture equipment;
- construction and operational vehicle movement;
- space for storage and handling of amines and handling of CO_2, including space for infrastructure to transport CO_2 to the plant boundary; and
- major plant deliveries and access around the Site.

5.8 In terms of the land required for laydown during construction of the CCS equipment, the laydown area would be determined and secured at the time of installation and would depend on the year of construction.

5.9 Further information regarding space requirements is provided in the following sections.

C4 Gas Turbine Operation with Increased Exhaust Pressure

5.10 The gas turbines may be unable to accommodate the increased backpressure due to the addition of CCS units. Therefore, the design for the carbon capture plant includes a booster fan/blower to compensate for the pressure drop through the CCS equipment (primarily in the absorbers, direct contact cooler and dampers) which is of the order of 140 mbar.

5.11 Based on the flue gas flow rate of around 1,168 m^3/s with a nominal pressure rise of 140 mbar a two stage axial fan with a power rating of approximately 17 MWe per GT, or 42 MWe in total has been included in the carbon capture plant power requirement.

5.12 As and when the carbon capture plant is designed in detail, detailed specifications for this fan will be developed. These would include provisions for the power drop across the absorber and the gas-gas re-heater, and the volume and mass flow rate of the flue gas into the absorber. Whilst it is not possible to provide detailed specifications for the booster fan at this stage without performing a more detailed design of the carbon capture plant, there is an adequate provision on the carbon capture plant for its installation and space (210m^2) for a booster fan / blower has been allocated to each train in the carbon capture plant.

C5 Flue Gas System

5.13 The following flue gas system is proposed for the CCS plant.

Isolation and Bypass Dampers

5.14 The flue gas exiting the HRSG is routed to a bypass or diverter damper, from where it may be directed either directly to the stack (*e.g.* during start up or fault conditions) but for normal operation through the CCS plant.

5.15 This arrangement allows for the CCS plant and the CCGT plant to have a reduced degree of mutual dependency, and to provide enhanced operability in safety and fault conditions. In the event of a major equipment fault such as the booster fan, the CCGT can be switched to bypass mode until the fault is corrected. Plant safety issues are also more readily addressed. Safety studies and dynamic analysis of the flue gas path will be necessary at the design stage, and will determine such parameters as fan control loops and the type and actuation speed of the bypass dampers.

Flue Gas Cooling

5.16 The absorption process requires a flue gas cooler to lower the flue gas temperature to around 45-55°C in order to enhance the CO_2 chemical absorption and to minimise amine degradation. The flue gas is routed from the HRSG to a Direct Contact Cooler (DCC), which quenches the flue gas to an acceptable temperature for absorption. A small slipstream of the circulating cooling water is routed through the DCC Water Filter to remove particulate build-up. A portion of this particulate free stream is returned to the DCC the other portion is headed to treatment plant. Cool, saturated flue gas from the DCC is extracted through the Blower which is required to overcome the frictional losses in the ducting, GGH, DCC and Absorber.

5.17 A gas-to-gas Ljungström type heat exchanger could be included prior to the DCC. Heat would be transferred from the hot untreated flue gas stream to the cold treated purified flue gas stream. This heat exchanger would reduce the duty of DCC and would improve the dispersion of the treated flue gases into the atmosphere. For this study this heat exchanger has not been sized for this study but could be considered if required in detailed design efforts.

CO_2 Absorber

5.18 The cooled flue gas from the DCC is fed to the bottom of the counter current Absorber where CO_2 in the flue gas is absorbed by the solvent. Flue gas enters near the bottom of the Absorber and flows upward through packed beds. CO_2 reacts chemically with the solvent and is absorbed into the bulk solution. Rich solvent leaves the bottom of the Absorber and is transferred to the Stripper by the Rich Solvent Pump.

5.19 Stripped flue gas, vaporized amine based solution and water travels through a chimney tray and enters the top packed bed. This third packed bed is the wash section of the column, where wash water is used to recover the vaporized amine and water. A Wash Water Circulating Pump circulates the wash water between the Absorber and Wash Water Cooler.

5.20 Flue gas is vented to the atmosphere via the stack on top of each Absorber at a temperature of around 45°C. No evaluation of the potential frequency of visible plumes from the final flue gas discharge from the CCS plant has been undertaken at this stage. This will be evaluated at the detailed design stage and if required appropriate mitigation employed.

CO_2 Stripper

5.21 Rich solvent leaves the bottom of the Absorber and is routed to the rich to lean amine solution cross heat exchanger which increases the efficiency of the process by heating the rich amine to >100°C using the heat in the lean amine stream from the Stripper. The preheated rich amine enters the Stripper below the wash section of the column through a liquid distributor and flows down through the packed beds counter-current to the vapour from the Reboiler releasing the absorbed CO_2. The lean amine from the bottom of the Stripper is transferred to the rich to lean solution cross heat exchanger, where it is cooled against the rich amine from the absorber train.

5.22 To remove impurities from the amine system, ~10% of the cooled amine is routed to the Amine Filter Package. This removes suspended solids and high molecular weight amine degradation products.

Stripper Overhead Condenser

5.23 The overhead vapour from the Stripper at ~100 °C and 0.8 barg is cooled to ~35 °C in the overhead Condenser), condensing some of the water content. The two-phase enters the separation drum (separating the product gas which is routed to the CO_2 Compression / Dehydration unit.

Amine Reclaimer

5.24 The amine based solution degrades in the presence of different elements that lead to amine oxidation to salts, thus a purification stage is necessary to prevent the accumulation of heat stable salts. The reclaimer is a kettle type reboiler where this purification process takes place. There is a feed of steam, water and sodium hydroxide to allow for part of the degraded amine based solution solvent recuperation through chemical reactions. The reclaimer is expected to operate on an intermittent basis when the content of dissolved salts be above curtained predefined value.

Centrifugal Compressor

5.25 The wet CO_2 from the Stripper Reflux Drum is routed to an intercooled CO_2 Compressor. The captured CO_2 is compressed to meet the delivery pressure required for the pipeline and remain dry.

Dehydration Unit

5.26 A dehydration package is needed for reducing the water content in the CO_2 stream to 50 ppm (wt.) to assure that condensation in the CO_2 pipeline does not occur. At this concentration, the dew point is at around -46 °C, which makes condensation unlikely.

5.27 A glycol based dehydration package, being a mature technology in natural gas dehydration processes, is well suited to be used for this application. For the expected operating temperatures, Triethylene-glycol (TEG) is better than other glycol based absorbents. This package is installed after the second intercooling stage of the CO_2 compression package. That way, the pressure remains below CO_2 critical point.

5.28 It is considered that there are no foreseeable technical barriers to retrofitting and integration of CCS into the flue gas system.

C6 Steam Cycle

5.29 A total supply of ~270 kg/s of low pressure (3.5 bar) steam at ~250 °C is required for the amine regeneration process.

5.30 In accordance with best practice guidance it is proposed that the steam is extracted from the CCGT IP/ LP crossover as steam conditions at this point would be suitable for the stripper re-boiler duty. Based on previous studies this approach using an integrated provision is considered to result in a reduced efficiency impact compared to the use of a standalone boiler.

5.31 The steam extraction would impact the power generated in the steam turbine as less steam flow rate would be expanded in the low pressure turbine section. It is estimated that the ST power output would decrease by circa 115 MWe. The steam extracted would be a considerable proportion of the total steam flow rate, therefore there are some technical issues which need to be addressed during detailed design, *i.e.* the effect on the ST steam operation and control, especially at part load.

C7 Cooling Water System

5.32 The amine based CCS process has a considerable cooling duty which is estimated at 1023 MWth. The main cooling demands within the CCS process comprise:

- flue gas DCC cooler;
- lean solution to absorber cooler;
- stripper overhead cooler; and
- CO_2 compression intercoolers.

5.33 Hybrid cooling towers are typically the preferred cooling system technology to meet these cooling demands; at this stage it is envisaged that these would be utilised at the Proposed Development as water is likely to be available from the River Aire based on the fact that the existing coal-fired power station licence allows more than twice the water volume to be abstracted that the proposed CCGT will.

5.34 The illustrative site layout in Figure 1 includes provisions for hybrid cooling towers.

C8 Compressed Air System

5.35 There is no requirement within a standard amine based CCS plant for any compressed air for process purposes, but only for the supply of instrument air and general service air to the CCS plant. This requirement shall be specified at the detailed design stage. Depending on the exact requirements, *e.g.* the number and duty of air actuated valves; this may be met by connecting to the compressed air services of the main CCGT plant, or by installing a new dedicated system for the CCS plant.

5.36 A new compressed air system would include but not be limited to compact air compressors (2x100%), air prefilters (2x100%), air after filters (2x100%), air inlet filters (2x100%), heatless regenerative dryers (2x100%), a wet receiver (1x100%), instrument air receivers (2x100%), pressure regulators (2-3) and air after coolers if required (2x100%).

5.37 Sufficient space has been allocated for a new compressed air system.

C9 Raw Water Pre-treatment Plant

5.38 The CCS plant will only have a small demand of make-up raw water. This water shall make up for small losses in of the amine/water solution loop caused by amine degradation or carry over; additional water will be required for cooling. This can be supplied from the River Aire.

5.39 In fact the process will generate water by condensation of moisture from the flue gas in the direct contact cooler (DCC) and the CO_2 compressor inter stage cooler knock-out drums. This water will be slightly acidic due to dissolved CO_2, but will be entirely suitable for treatment in the main CCGT plant WTP. No dedicated CCS WTP or pre-treatment plant is therefore foreseen.

C10 Demineralisation Plant

5.40 As discussed in Section 5.9, facilities provided for the Proposed Development are considered sufficient to meet the make-up water requirements of the CCS plant. The carbon capture and compression processes are not large demineralised water consumers. Additional water requirements will be to replace the water removed during the amine reclaiming process. At present this is estimated to be approximately 34.5 tonne/hr peak per train as per Fluor's Econoamine FG process, although there are studies[9] which suggest that demin water quality is not required for the amine solution make-up water and only good quality water is required. Should demin water quality be required, there is still sufficient space in the proposed layout to include a dedicated water treatment plant which is estimated to take up around 8 m x 12 m. The required water quality and quantity shall be specified at detailed design phase.

C11 Waste Water Treatment Plant

5.41 It is expected that the detailed design of the CCS equipment will include appropriate surface water drainage systems including oil interceptors as necessary and consistent with surface water drainage systems for power stations in general. Space provision for site drainage *e.g.* surface water and process water drains has been included in the worst case footprint allocation for each piece of equipment.

5.42 Waste water will be generated from the cooling of the flue gas resulting in partial condensation of water vapour within the direct contact cooler. The volume of wastewater generated will vary with ambient conditions but is not likely to exceed 40 t/h depending on the gas turbine selected. The following Table 5.1 lists the waste water treatment requirements.

Table 5.1: Waste Water Output

Description	Units	Value
Drain Water from CO_2 compression CCS plant #1	kg/s	10
DCC CC Train 1 drain	kg/s	12
DCC CC Train 2 drain	kg/s	12
DCC CC Train 3 drain	kg/s	12
Total Reclaimer waste (sludge)	m^3/h	11.9
Active carbon consumption	kg/day	866

5.43 The waste water drain will be relatively clean although may have a slightly elevated pH. It is envisaged it will be routed to the Eggborough Power Station effluent treatment plant for pH neutralisation prior to discharge or could be used as raw water for the WTP without further treatment.

5.44 The standard amine based process includes a reclaimer for recovery of amine based solution and removal of degradation products, solids and salts formed in the carbon capture process. This operation will generate a low volume effluent stream which it is envisaged will be directed to the on-site effluent treatment plant.

[9] Source: IEA Greenhouse Gas R&D Programme (IEA GHG), "CO_2 capture ready plants", 2007/4, May 2007.

5.45 Activated carbon is also consumed in the active carbon filters for the circulating amine based solution. A slip-stream is constantly directed to a mechanical prefilter and then to the active carbon filter for removal of solids delaying the reclaiming activity. It is estimated that 0.08 kg of carbon per tonne of captured CO_2 shall be consumed. This solid waste material shall be disposed of for off-site regeneration/recycling via a licensed waste contractor.

5.46 If appropriate, this stream could be combined with the condensed water vapour stream if that would neutralise the pH of both streams for example, although the details would be confirmed at the detailed design stage for the CCP. The detailed design would also identify whether any modifications to the Eggborough effluent treatment system were required at that time.

5.47 The provision of space for any waste water treatment is included in the illustrative site layouts in Plate 6.

C12 Electrical

5.48 In addition to the utilities described previously, the CO_2 capture system will require the following utilities:

- electrical power distribution system; and
- fire protection and monitoring system.

5.49 The total power requirement of the CCS plant is approximately 124 MW. Further detail of individual users is presented in Table 5.2.

Table 5.2 Electrical Requirements

Description	Units	Value
CO_2 compressors	MWe	66
Booster Fan (3x unit)	MWe	42
Hybrid Coolers (for 3x trains)	MWe	3
Amine based solution circulating pumps	MWe	6
Other miscellaneous power demands	MWe	7
Total	**MWe**	124

5.50 It is currently proposed that the electrical demand of the CCP is taken directly from the output of the CCGT, reducing the export capacity to the National Grid accordingly.

C13 Plant Pipe Racks

5.51 Space provision for plant pipe racks has been included in the footprint allocation for each piece of equipment and is shown in Figure 1.

C14 Control and Instrumentation

5.52 The control and instrumentation system for the carbon capture plant is anticipated to be incorporated into the Distributed Control System of the Proposed Development, *i.e.* the control room. However, space is available on the carbon capture plant for standalone control equipment should this be required.

C15 Plant Infrastructure

5.53 It is anticipated that major plant may be delivered by road.

5.54 The provision of space for additional plant infrastructure is illustrated in the illustrative site layout in Figure 1.

5.55 The Site is accessible from the existing road network and is not considered to have any access constraints which could impede any future construction activities. The final provisions for plant infrastructure will be detailed in the final design of the carbon capture plant.

6.0 TECHNICAL ASSESSMENT – CO_2 STORAGE

6.1 The maximum theoretical volume of CO_2 anticipated to be captured during the lifetime of the Proposed Development is 223 million tonnes (assuming approximately 6.5 Mt CO_2/year from the three CCGT units, an average lifetime capacity factor of 90% and a 35 year design lifetime of the power station). In reality, it is unlikely that the CCGT will operate to a 90% load factor over its entire lifetime and a 60% load factor is more realistic, which would equate to a total CO_2 volume of approximately 149 Mt.

6.2 The UK's major potential sites for the long-term geological storage of CO_2 are offshore depleted hydrocarbon (oil and gas) fields and offshore saline water-bearing reservoir rocks / aquifers.

Oil and Gas Fields

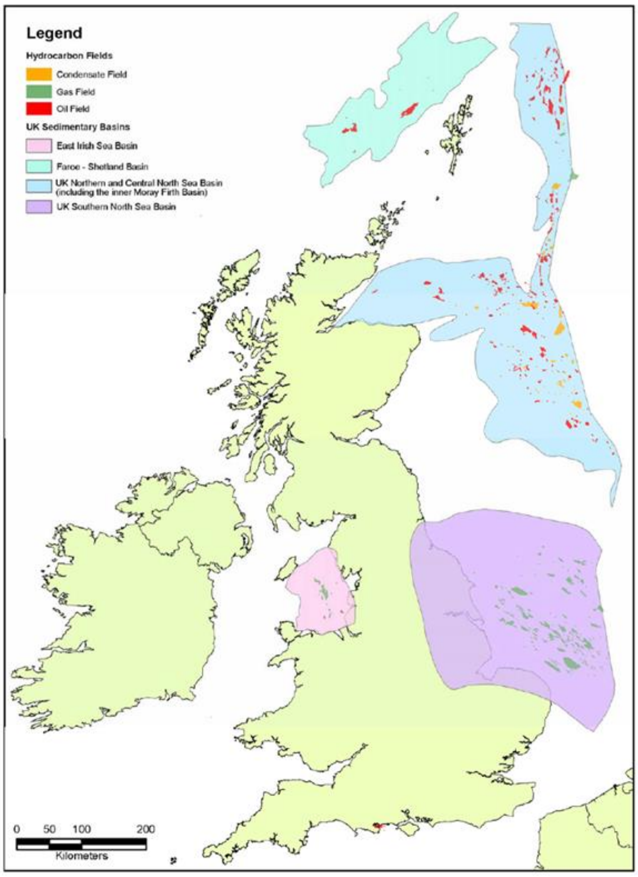
6.3 Oil and gas fields are regarded as prime potential sites for CO_2 storage for the following reasons:

- they have a proven seal which has retained buoyant fluids, in many cases for millions of years; and
- often a large body of knowledge and data regarding their geological and engineering characteristics has been acquired during the exploration and production phases of development.

6.4 As shown in **Plate 6** most of the UK's large offshore oil fields are in the Northern and Central North Sea Basin. However, there are three major fields (Clair, Foinaven and Schiehallion) in the Faroes-Shetland Basin, two (Douglas and Lennox) in the East Irish Sea Basin, and one (Beatrice) in the Inner Moray Firth Basin. The UK's offshore gas fields occur mainly in two areas: the Southern North Sea (SNS) Basin and the East Irish Sea Basin. However, there is also one major gas field (Frigg) in the Northern and Central North Sea Basin.

6.5 The DECC CCR guidance suggests that the simplest and most appropriate means of demonstrating there are "no known barriers" to CO_2 storage is by delineating on a map a suitable storage area in either the North Sea or Irish Sea (Morecambe Bay). Within this delineated area, there should be at least two fields or aquifers, with an appropriate CO_2 storage capacity, which have been listed in either the "valid" or "realistic" categories in the DTI's 2006 study of UK Storage Capacity "Industrial Carbon Dioxide Emissions and Carbon Dioxide Storage Potential in the UK", October 2006 (DTI Study 2006), which is provided in Annex 1D of the CCR Guidance.

Plate 5: The location of offshore hydrocarbon fields and the major oil and gas-bearing sedimentary basins



6.6 The Proposed Development is located in the north of England approximately 30 km west of the start of the Humber estuary; therefore the nearest hydrocarbon fields to the Proposed Development are located in the Southern North Sea Basin. The 2006 DTI Report lists a number of storage options within the gas and condensate fields with the basin that could be use either individually or in combination to store the CO_2 from the Proposed Development. Of these fields, Indefatigable and Lemen could store the entire CO_2 production of the Proposed Development over its entire lifetime on their own. These fields are both listed as 'realistic' in the DTI report. The indicative storage capacity of both fields is shown in Table 6.1 below.

Table 6.1 Capacity of Proposed Geological Storage Areas

Field Name	Total Volume of CO_2 emitted / 10^6 tonnes	Capacity of Geological Storage Area / 10^6 tonnes	%
Indefatigable Gas Field	Up to 223	357	62
Leman Gas Field	Up to 223	1,203	19

6.7 The DTI study defines "realistic" capacity (p.6) as: *"Realistic capacity applies to a range of technical (geological and engineering) cut-offs to elements of an assessment, e.g. quality of the reservoir (permeability, porosity, heterogeneity) and seal, depth of burial, pressure and stress* *regimes, size of pore volume of the reservoir and trap, nature of the boundaries of the trap and whether there may be other competing interests that could be compromised by injection of CO_2 (e.g. existing subsurface resources such as oil and gas, coal, water or surface resources such as national parks). This is a much more pragmatic estimate that can have some degree of precision, and gives important indications of technical viability of CO_2 storage."*

6.8 It is recognised that in the future there may be competing interest for the identified CO_2 storage sites, as other carbon capture and storage projects become operational. It is also recognised that other CCR applications may also have identified the same geological fields for CO_2 storage capacity. However, according to the DECC Website (now the Department for Business, Energy and Industrial Strategy (BEIS), https://itportal.decc.gov.uk/EIP/pages/c02.htm) neither of these fields has been identified as potential storage locations.

6.9 Notwithstanding the above, the CCR report submitted with the Application to vary a Consent under the Section 36C of the Electricity Act 1989 for Damhead Creek 2 power station in Kent in 2016 does identify the Leman field as a potential CO_2 storage location. However, according to the DTI report, the Leman field has sufficient capacity (1203 Mt) to store both the maximum quantity of CO_2 identified as potentially generated by that development (141 Mt) and from the Proposed Development (227 Mt).

6.10 The storage assessment will be reviewed on an ongoing basis as part of the two yearly Status Reports (to be secured by requirements in the DCO), with a view to incorporating developments in the updated design for the carbon capture plant for the Proposed Development.

7.0 TECHNICAL ASSESSMENT – CO_2 TRANSPORT

7.1 There are various options available for transporting CO_2 from point of capture to final geological storage, including on-shore transportation by pipeline, or potentially use of rail or road tankers and off-shore transportation by pipeline or shipping.

7.2 It is proposed that the CO_2 captured from the Proposed Development will be transported to the storage site via pipeline. Transport via road or rail is not considered to be economically feasible or realistic given the volumes of CO_2 that would be transported. It is considered that tankers may have a role in smaller (demonstration scale) projects, but for larger volumes pipelines are the only practical option.

7.3 An assessment of an indicative route has been assessed taking into account the following considerations:

- an exit point from the Site that is unlikely to be blocked by future developments outside of the Site boundary; and
- the presence of residential areas, natural and built linear infrastructure (such as rivers, rail lines and motorways), and designated sites, such as Sites of Special Scientific Interest (SSSI), Special Areas of Conservation (SAC), Special Protection Areas (SPA), Ramsar Sites, National Nature Reserves (NNR), Designated Parks and Gardens.

7.4 In accordance with the DECC guidance an indicative route corridor of 1 km in width has been shown up to approximately 10 km. This corresponds to a point on the route that had been proposed for the Yorkshire – Humber CO_2 pipeline. Whilst it is recognised that this pipeline is now unlikely to go ahead in the short to medium term (following the refusal of its DCO application for the onshore section), that refusal was solely on grounds related to the case for the pipeline and the lack of the White Rose Carbon Capture and Storage Project to provide the likely 'initial' CO_2. The route (etc) of the Yorkshire – Humber CO_2 pipeline was generally 'approved' by the Examining Authority and Secretary of State. From that point a 10 km corridor to the coast is shown centred on the route of the Yorkshire - Humber pipeline, since this route has previously been evaluated for that project. This route is shown on Figures 3 and 4.

7.5 As the DCO application for the Yorkshire – Humber pipeline development was refused in January 2017, no assumptions have been made about being able to use that pipeline or exactly the same route. However, the route was previously considered to be potentially viable.

7.6 It is therefore considered that the route still has potential, providing that the reasons for refusal of the DCO (which as noted above related principally to the lack of likely CO_2 emitter) could be adequately addressed. For the purposes of this report, only the maximum corridor allowable under the DECC guidance has been assumed.

7.7 From an indicative landfall in the vicinity of Barmston on the Yorkshire coast a pipeline route to both identified fields has been identified that avoids the major infrastructure in the North Sea (production platforms and off-shore windfarms). These potential routes are shown on Figure 5 & 6.

8.0 ECONOMIC ASSESSMENT – RETROFITTING CARBON CAPTURE TECHNOLOGY, TRANSPORT AND STORAGE

8.1 The principal economic driver currently available for CCS viability without Government fiscal support is the price of carbon. The price of carbon needs to have achieved a high enough monetary value to make carbon capture and storage economically viable. The carbon market remains very volatile and indeed some of its leading proponents are questioning the success of the system in delivering value for money carbon reductions.

8.2 Regulation and financial incentives are two other options to assist with the development of carbon capture technology after the initial demonstration phase. While the current Emissions Performance Standard (EPS) is set at a level that does not require the use of CCS on efficient new build gas-fired power stations (450 g/kWh at baseload), this may change in the future as both the EU and the UK Government continue to aspire to decarbonise electricity generation.

8.3 These issues are however beyond the control or scope of the Proposed Development. The Applicant therefore proposes to draw on existing economic modelling developed over a number of sites. Such modelling provides indications of the likely range of costs associated with the introduction of CCS facilities. These models include fuel price; carbon price; capture costs; transport costs and storage costs. Models have also looked at Enhanced Oil Recovery projections; network supported projections and variations around re-use of existing assets or construction of new assets. There is also the probability that costs will diminish as implementation moves from demonstration to roll out of installed capacity.

8.4 The overall view at present suggests that:

- CCGT capital costs without carbon capture will be in the range of £400 – £600 per kW;
- with CCS, costs will be in the range of £1,000 – £1,800 per kW; and
- the cost of carbon capture, transport and storage is anticipated to be £50/ tonne - £70/ tonne.

8.5 In accordance with the CCR guidance, using the information available the following have been compared to assess the economic feasibility of operational CCS at the Proposed Development, as shown in Table 8.1:

- cost of electricity generation without CCS (and assuming that EU Allowances must be purchased for 100% of the CO_2 emitted by the Proposed Development and no free allowances are allocated); with
- worse case cost of electricity generation with CCS (including cost of retrofitting carbon capture equipment, cost of CO_2 transport and cost of CO_2 storage).

Table 8.1: Economic Feasibility of Operational CCS

Costs / £ per tonne CO_2	Scenario A – current carbon price		Scenario B – required carbon price	
	No CCS	CCS	No CCS	CCS
Carbon Allowances[10]	26[11]	N/A	57	N/A
Retrofitting capture equipment (construction and operation)	N/A	35	N/A	35
CO_2 Transport predominantly via pipeline	N/A	10	N/A	10
CO_2 Storage	N/A	12	N/A	12
Total Cost	**26**	**57**	**57**	**57**

8.6 Based on data obtained from the Kingsnorth, Longannet and Peterhead carbon capture competition publicly available documents, the capital cost of full chain CCS is £1.1-1.3 billion (based on 300 MW scale). Based on a scaling per tonne of captured CO_2 and considering the pipeline length to the proposed storage location, a capital cost of circa £1.2 - 1.6 billion is estimated for Eggborough CCGT assuming up to 149 Mt of CO_2 captured.

8.7 The operating and pumping costs of the CCS plant and pipeline are estimated to be £57/t. The costs estimates for CCS construction and operation at the Proposed Development are considered to be comparable to those of other CCS projects.

8.8 The information presented above confirms that the cost of electricity from the Proposed Development will be increased with the addition of CCS, due to the additional capital and operating costs of the carbon capture plant, pipeline and injection; this of course is to be expected.

8.9 The results also indicate that the addition of CCS at the Proposed Development only starts to potentially become economically feasible at a cost of carbon in excess of £57/tonne and that assumes that the capital costs can be spread over 35 years of CO_2 capture at high load factors; for lower load factors on the CCGT the volume of CO_2 captured over the plant lifetime is correspondingly reduced, rendering the cost per tonne of CO_2 correspondingly higher.

8.10 Therefore, should the load factors drop from 90% (yielding up to 223 Mt CO_2) to (for example) 35% over the plant lifetime, this would reduce the captured CO_2 volumes to 75 Mt, which in turn would increase the lifetime CCS costs per tonne by a factor of 2.6. Similarly, a 60% load factor

[10] EU Allowances under the EU Emissions Trading Scheme (EU ETS) / UK Carbon Floor Price
[11] Assuming £8/tonne EU ETS carbon cost and £18/tonne UK Carbon floor price

would yield 151Mt of CO_2 for storage which would increase the lifetime CCS costs per tonne by a factor of 1.5.

8.11 Comparable models developed for other power station developments in the UK to date have also utilised lifetime electricity costs, 100% carbon purchase assumptions and varying ranges of CO_2 cost from £0/tonne - £135/tonne. In these models, variation ("stressing") is added to fuel pricing, capital costs and baseline costs for transport and storage. Similar models have been utilised for the Carbon Capture and Storage Network for Yorkshire and Humber transport network solution study and the 'Opportunities for CO_2 Storage around Scotland' study. These all confirm that the cost of carbon needs to be in excess of £57/tonne for full economic feasibility, rising beyond that if low load factors are taken into account.

8.12 These prices can be readily compared with data from external forecasters, *e.g.* the independent McKinsey Report "Pathways to a Low Carbon Economy" (2009) and the "Cost Abatement Curve". In particular Exhibit 8.1.4 of the McKinsey Report indicated an abatement cost of 50 Euros per tonne CO_2 for a gas CCS new build (by 2030), again assuming higher load factors are taken into account. Over time, it is anticipated that the required price of carbon may reduce toward the order of 50 Euros per tonne (predicted by external forecasters) as knowledge of carbon capture technology and full chain CCS advances, however, currently there are uncertainties as to rate of progression along that learning curve. It is considered that in the future some form of direct fiscal support for carbon capture facilities may be required to be put in place, *e.g.* a Contract for Difference, capital grants, soft loans on favourable terms, etc.

8.13 Significant variances in modelled economic viability can occur as a result of fluctuations in:

- the selected load factor for the proposed power station (with around 18% variance in different models);
- fuel prices, which exhibit -20% to +30% variance;
- capital costs, which exhibit a 10% variance; and
- a potential 10% – 20% increase in fuel consumption costs to power the future CCS system.

8.14 The variables are substantial and are prone to external force variance. However, it is clear that there is a stronger viability if a CCS network is developed, potentially utilising redundant existing pipeline and injection assets wherever possible. By developing a transport asset for a network, considerable costs are shared, and financing is potentially more readily available, as a number of partners share the risk and the opportunity. Some reports suggest that shared storage sites would also bring storage costs down by one third; although storage costs are expected to represent only approximately 10 – 24% of total costs.

8.15 These significant variance levels further serve to demonstrate the early risks associated with the current level of technology development and lead to economic viability assessments in excess of £57/tonne.

8.16 A number of financial institutions (Deutsche Bank, New Carbon Finance, UBS) expect the price of carbon to be at £30/tonne – £35/tonne by 2030. At this stage, analysts anticipate the cost of carbon capture to have dropped by up to 50% if First Of A Kind deployment has taken place by then. This is thought to lead to a cost in the region of £28/tonne – £35/tonne of CO_2 abated in 2030. If these two factors do coincide then the cost of carbon capture will have reached a neutral position for the Proposed Development and similar CCGTs.

8.17 The study 'Opportunities for CO_2 Storage around Scotland' concludes that Government support in the region of £100 m/year is required to develop the carbon capture, transport and storage facilities, to move this technology from demonstration to full implementation (dependent on the price of carbon). This is therefore the level of financial support considered by this study to be necessary if the industry is to move from concept to practical, economic implementation.

8.18 An important feature of an economic carbon transport system will be a network pipeline solution. Assessments estimate that the cost of shipping carbon would be in the range of £7.4 /tonne – £8.6 /tonne. Transporting carbon via pipeline would cost £1.9 /tonne – £3.7 /tonne based on a network capable of handling 20 million tonnes per annum. A single point-to-point pipeline would cost in the order of 30% more. Additionally, reaching a point of economic viability will require new alliances of businesses across the CCS supply chain.

8.19 In summary, deployment of CCS will add significant cost to both the capital outlay and the operation of any power station and currently is not considered to represent the Best Available Technique (BAT) for the Proposed Development. However, subject to market conditions, based on high level assumptions, the Proposed Development can in principal achieve an economically viable carbon capture solution if required in the future, as the site:

- has sufficient space allocated and reserved for the potential retrofit of CCS if required; and
- has access to potentially secure geological carbon storage facilities that have capacity for the foreseeable future.

8.20 Should CCS technology be commercially deployed across the UK in the future, the proximity of the Proposed Development site to other operational and proposed power generation facilities and industrial CO_2 emitters may also mean that a transport hub could be employed for the region, further reducing the CO_2 transport costs associated with this Proposed Development in isolation.

8.21 The assessment therefore demonstrates that there are no known economic barriers to capture, transport and storage of emissions of CO_2 from the Proposed Development and that CCS technology could theoretically be retrofitted at a later date.

9.0 HEALTH AND SAFETY ASSESSMENT

9.1 It is likely that the onshore and offshore CO_2 transport from the Site will be in a 'dense phase', *i.e.* at a pressure greater than 73.9 bar.

Pipeline

9.2 The DECC CCR Guidance Note states that, until the Health and Safety requirements of pipelines conveying dense phase CO_2 have been considered in more depth, such pipelines should be considered as conveying 'dangerous fluids' under the Pipeline Safety Regulations 1996 (PSR), and 'dangerous substances' under the Control of Major Accident Hazards Regulations 1999 (as amended) (COMAH). The pipeline would therefore be considered to be a Major Accident Hazard Pipeline (MAHP).

9.3 Therefore, when undertaking the detailed design of the pipeline route, it is recognised that the pipeline operator must pay due attention to the following potential requirements:

- installation and frequency of emergency shut-down valves;
- the preparation of a Major Accident Hazard Prevention Policy (MAPP); and
- ensuring the appropriate emergency procedures, organisation and arrangements are in place.

9.4 In addition, the Local Authority, which would be notified by the HSE of a MAHP, must prepare an Emergency Plan.

9.5 It is considered that, based on the evaluation undertaken on behalf of National Grid for the consenting of the Yorkshire – Humber carbon pipeline, that the H&S implications and risks of any dense phase carbon pipeline can be appropriately mitigated through the design of the pipeline. Specifically, the Safety Statement[12] submitted with the Environmental Statement in support of the DCO for the pipeline identified the principal risks as being small leaks from the pipeline that could be mitigated through appropriate monitoring and maintenance Similarly, based on hazard release modelling of comparable CO_2 compression facilities, potential accident scenarios can be evaluated and potentially significant effects can be mitigated; these would be undertaken at the detailed design phase of any CCS transport network. The Health and Safety Executive in their assessment of the major hazard potential of carbon dioxide (available at: http://www.hse.gov.uk/carboncapture/assets/docs/major-hazard-potential-carbon-dioxide.pdf) concludes that the major accident potential of CO_2 is in line with other hazardous substances.

On Site

9.6 There is the potential for dense phase CO_2 to be present in pipework or vessels on site once it has been captured and compressed prior to transport. Whilst CO_2 is not currently classified as hazardous, DECC and the HSE recognise that an accidental release of large quantities of CO_2 could result in a major accident.

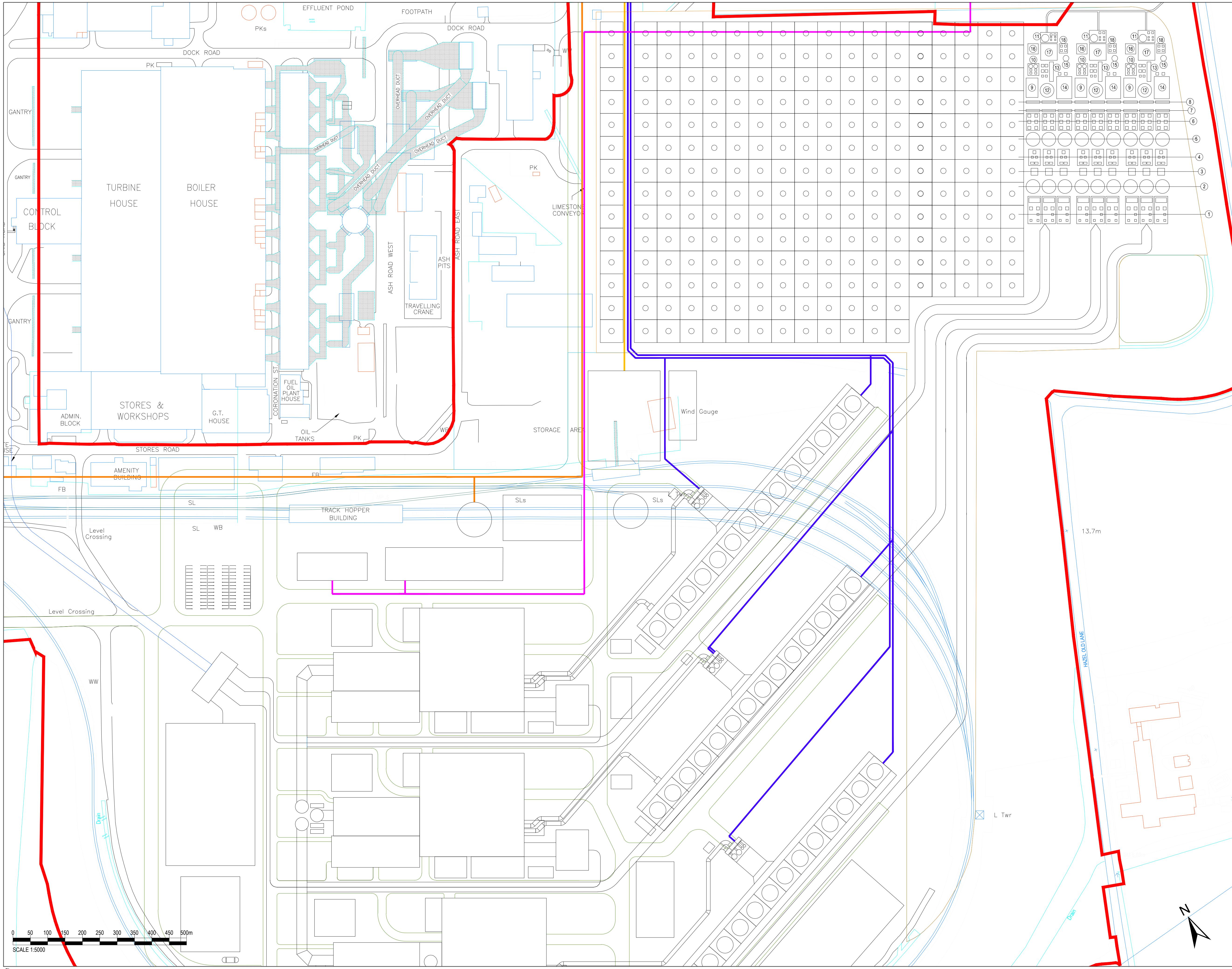
[12] Available at: https://infrastructure.planninginspectorate.gov.uk/wp-content/ipc/uploads/projects/EN070001/EN070001-000386-6.4.7%20Safety%20Statement.pdf

9.7 No bulk storage of dense or gaseous phase CO_2 is proposed in the initial CCS design for the Development. The only 'stored' CO_2 on site would therefore be the inventory in the capture plant and on-site pipework, and this is envisaged to be considerably less than five tonnes. On this basis therefore, it is concluded that even if CO_2 were to be reclassified in the future, utilising the carbon capture technology selected for the Proposed Development (post-combustion capture based on amine based solution), the proposed design for the Proposed Development would not fall under the HSC regime.

10.0 REVIEW

10.1 The Applicant is committed to review and report on the effective maintenance of the Eggborough Power Station CCR status within three months of the power station commencing commercial operations and periodically every two years thereafter. This is secured by requirements in the draft DCO (Application Document Ref. 2.1).

Figure 1: Carbon Capture Plant Indicative Layout



THIS DRAWING IS TO BE USED ONLY FOR THE PURPOSE OF ISSUE THAT IT WAS ISSUED FOR AND IS SUBJECT TO AMENDMENT

LEGEND

1. GAS CONDITIONING STATION
2. FLUE GAS COOLER
3. FLUE GAS BLOWER
4. QUENCH WATER HEAT EXCHANGER W/FILTER STATION
5. ABSORBER
6. RICH / LEAN SOLVENT PUMPS
7. SOLVENT CROSS EXCHANGER
8. LEAN AMINE COOLER
9. RECLAIMER
10. DOSING POT
11. AMINE STORAGE TANKS AND PUMPS
12. DESORBER UNIT
13. STRIPER CONDENSER
14. RE-BOILER
15. OVERHEAD ACCUMULATOR
16. DEHYDRATION UNIT/DE-OXYGENATION UNIT
17. CO2 COMPRESSOR
18. WASTE WATER PUMP
19. FIN FAN COOLERS

KEY

THE ORDER LIMITS

FICHTNER
CONSULTING ENGINEERS LIMITED

Kingsgate, Wellington Road North,
Stockport, Cheshire, SK4 1LW, UK
Tel: 0161 476 0032
Website: www.fichtner.co.uk

Purpose of Issue
DCO APPLICATION

Client
EGGBOROUGH POWER LTD

Project Title
EGGBOROUGH CCGT DCO

Drawing Title
CARBON CAPTURE PLANT INDICATIVE LAYOUT

Drawn	Checked	Approved	Date
SC	JW	KC	30/03/2017

AECOM Internal Project No.	Scale @ A3
60506766	1:2500

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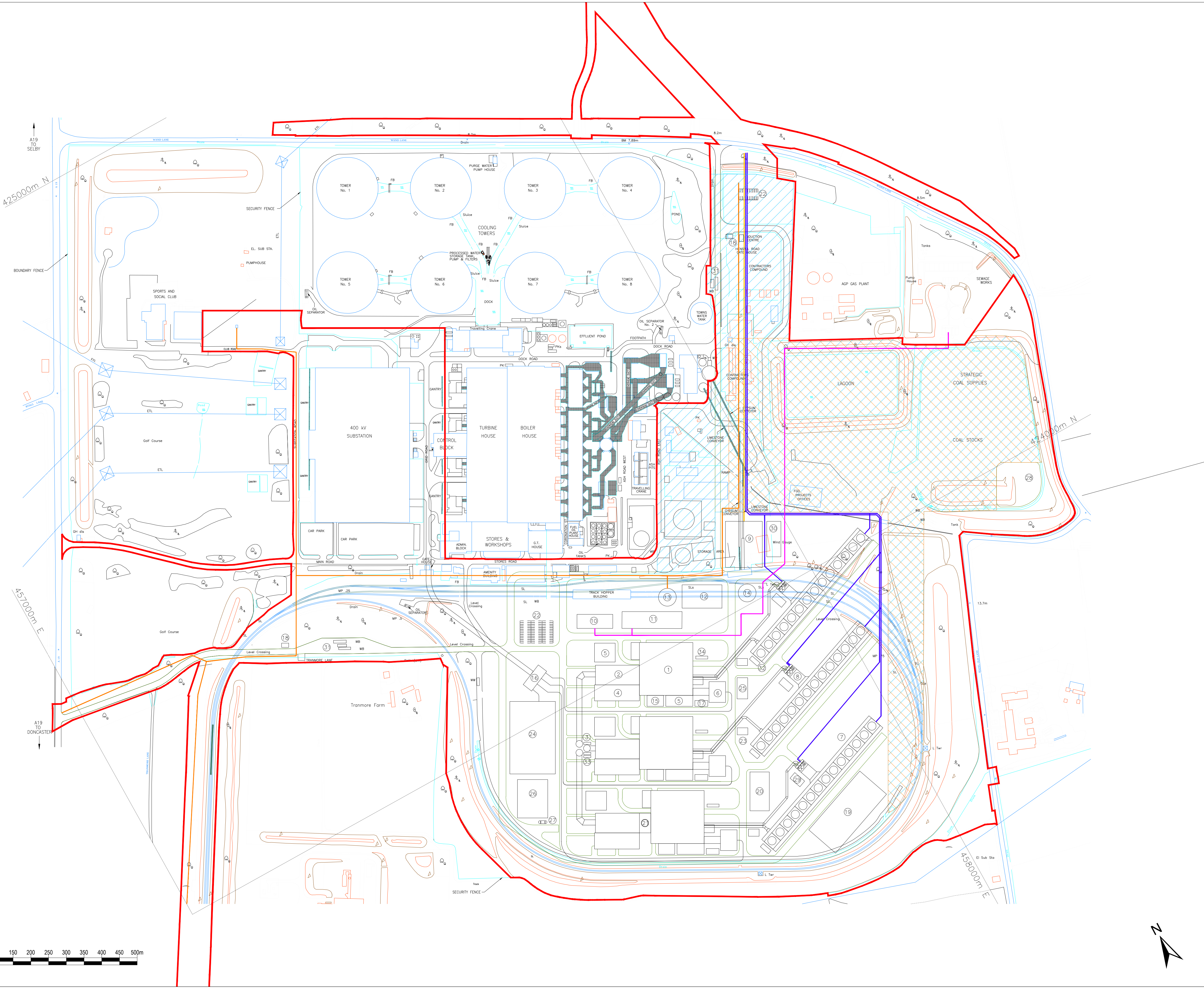
Drawing Number: FIGURE 1
Rev: 01

Figure 2: Site Area Available for Carbon Capture



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LEGEND

	PLANT DESCRIPTION
1	TURBINE HALL
2	HRSG
3	STACK
4	FEEDWATER PUMP BUILDING
5	ELECTRICAL BUILDING
6	GENERATOR TRANSFORMER
7	HYBRID COOLING TOWERS
8	CW PUMPS
9	GAS RECEIVING AREA
10	WORKSHOP & STORES
11	ELECTRICAL, CONTROL ROOM & ADMIN BUILDING
12	WATER TREATMENT PLANT, FIRE PUMPS & LABORATORY
13	RAW & FIRE WATER TANK
14	DEMIN WATER TANK
15	AIR INTAKE FILTER
16	GIS ELECTRICAL BUILDING
17	DIESEL GENERATORS
18	GATEHOUSE
19	FIREWATER & STORMWATER RETENTION BASINS
20	WASTE WATER TREATMENT PLANT
21	SPACE FOR BYPASS STACK (1xGT ONLY)
22	CAR PARKING
23	CCCW COOLERS
24	PEAKING PLANT
25	AUXILIARY BOILER
26	BLACK START FACILITY
27	DIESEL TANK FOR BLACK START DIESEL GENERATOR
28	INFILTRATION/ATTENUATION AREA
29	COOLING WATER SAMPLING & DOSING
30	GAS COMPRESSORS
31	WEIGHBRIDGE
32	COOLING WATER ELECTRICAL MODULE
33	CEMS CONTAINER
34	H_2/CO_2 BOTTLE STORAGE

KEY

- THE ORDER LIMITS
- SEWAGE TO HENSHALL SEWAGE WORKS
- CW (MAKE-UP & PURGE)
- GAS SUPPLY LINE
- TOWNS WATER & BOREHOLE WATER
- UNDERGROUND CABLE
- LAYDOWN FOR CCGT
- LAYDOWN FOR FUTURE CCS
- POTENTIAL RAIL MODIFICATIONS

NOTE:

PIPE & CABLE RACKS/SLEEPERWAYS NOT SHOWN FOR CLARITY

Purpose of Issue
DCO APPLICATION

Client
EGGBOROUGH POWER LTD

Project Title
EGGBOROUGH CCGT DCO

Drawing Title
SITE AREA AVAILABLE FOR CARBON CAPTURE

Drawn	Checked	Approved	Date
SC	JW	KC	30/03/2017
AECOM Internal Project No. 60506766		Scale @ A3 1:2500	

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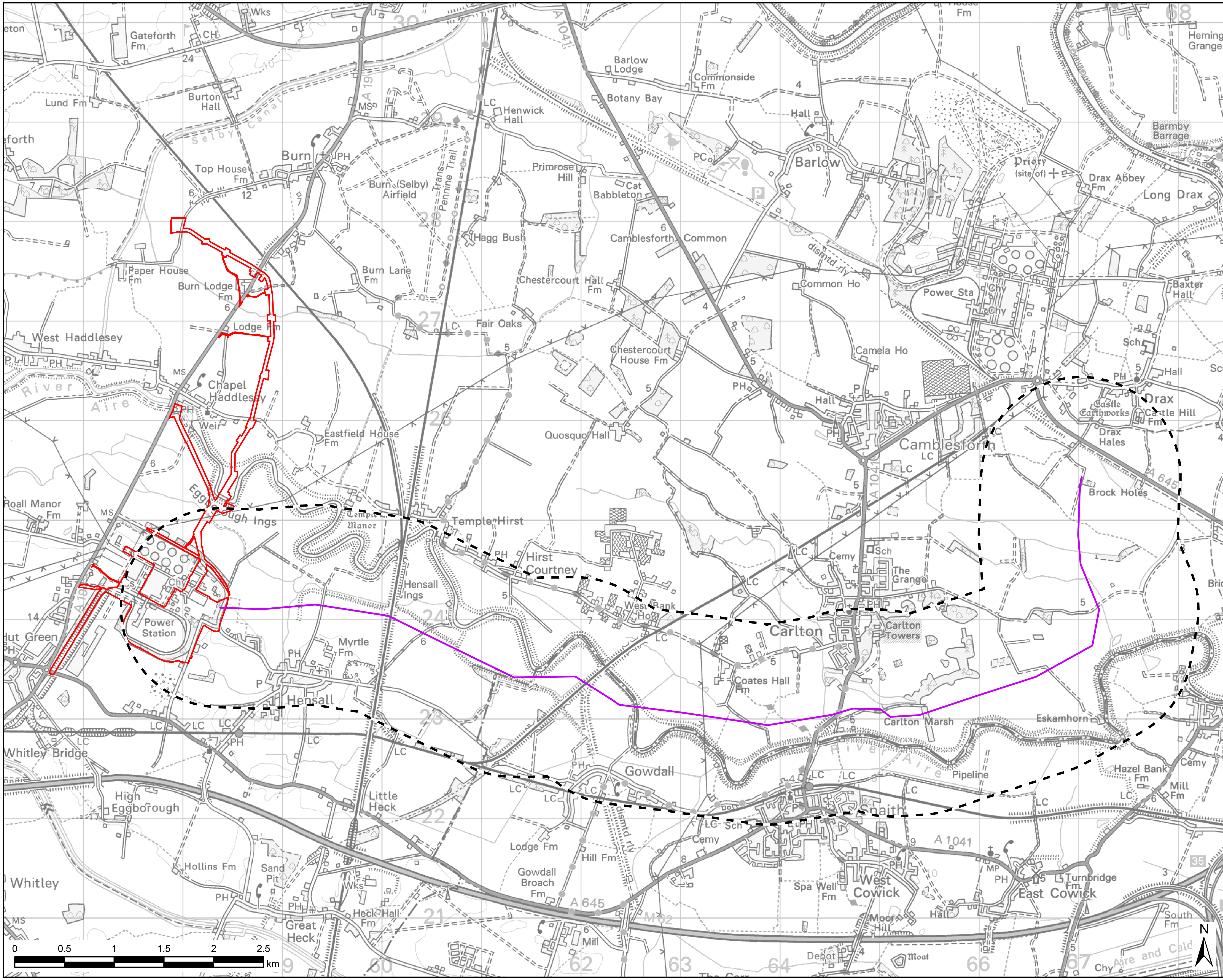
Drawing Number	Rev
FIGURE 2	01

Figure 3: Indicative CO_2 Pipeline Route Site to 10 km



File Name: K:\5004 - Information Systems\60506766_Eggborough_CCGT_DCO\02_Maps\DCO Application_DCO Application Document\Figure_3_Proposed_CO2_Pipeline_Route_to_10km.mxd

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LEGEND

- The Order Limits
- Proposed CO2 Pipeline Route to 10km
- 1km CO2 Pipeline Route Corridor

Purpose of Issue

DCO APPLICATION

Client

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Project Title

EGGBOROUGH CCGT DCO

Application Document Ref

PROPOSED CO2 PIPELINE ROUTE TO 10KM

Drawn	Checked	Approved	Date
JW	BB	JS	19/05/2017

AECOM Internal Project No.	Scale @ A3
60506766	1:35,000

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FIGURE 3

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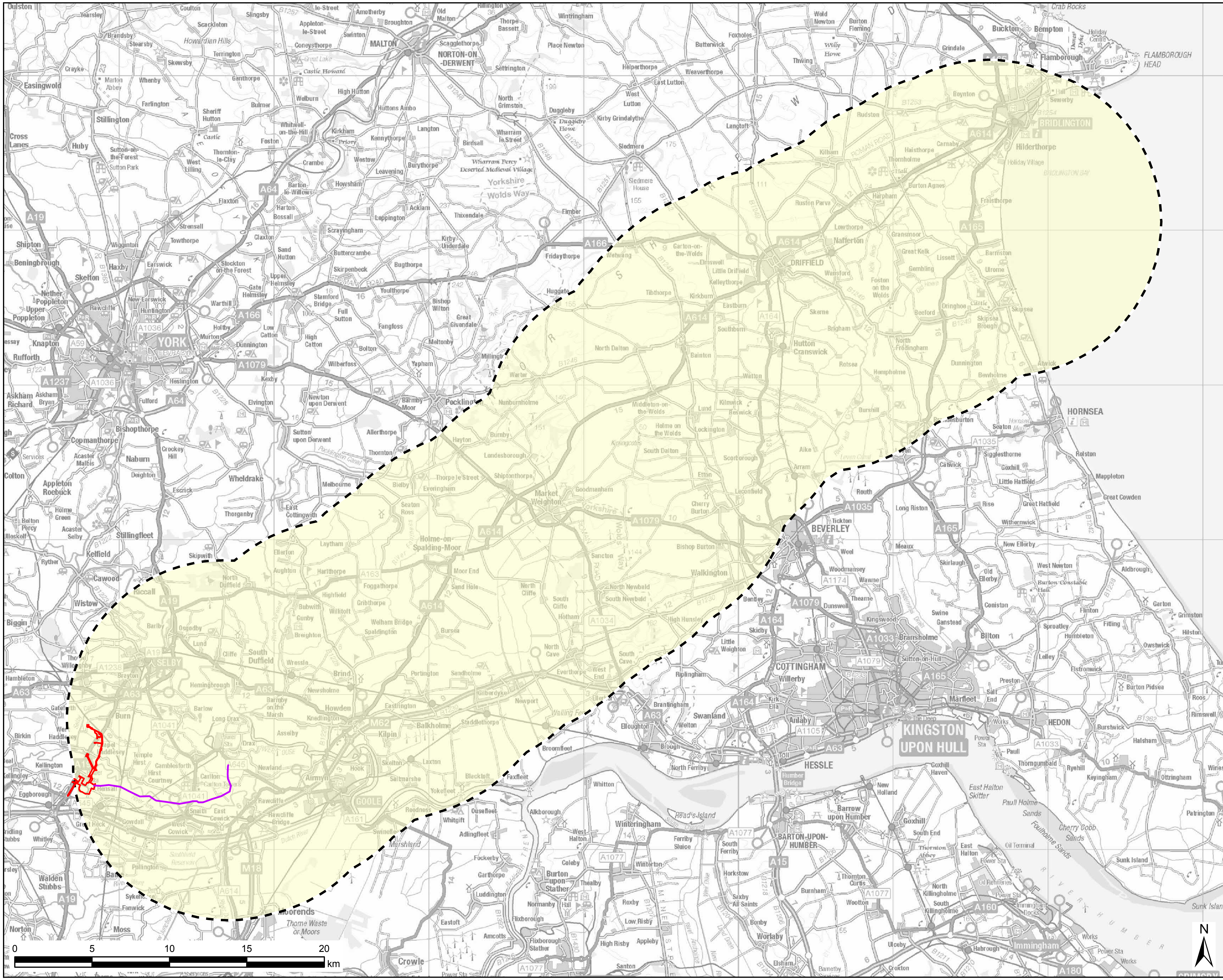
Figure 4: Indicative CO_2 Pipeline Route 10 km to Coast



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LEGEND

- The Order Limits
- 10km CO2 Route Corridor
- Proposed CO2 Pipeline Route to 10km

Purpose of Issue
DCO APPLICATION

Client
EGGBOROUGH POWER LTD

Project Title
EGGBOROUGH CCGT DCO

Application Document Ref
CO2 PIPELINE ROUTE

Drawn	Checked	Approved	Date
JW	BB	JS	09/03/2017

AECOM Internal Project No.	Scale @ A3
60506766	1:225,000

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Drawing Ref
FIGURE 4

Rev
01

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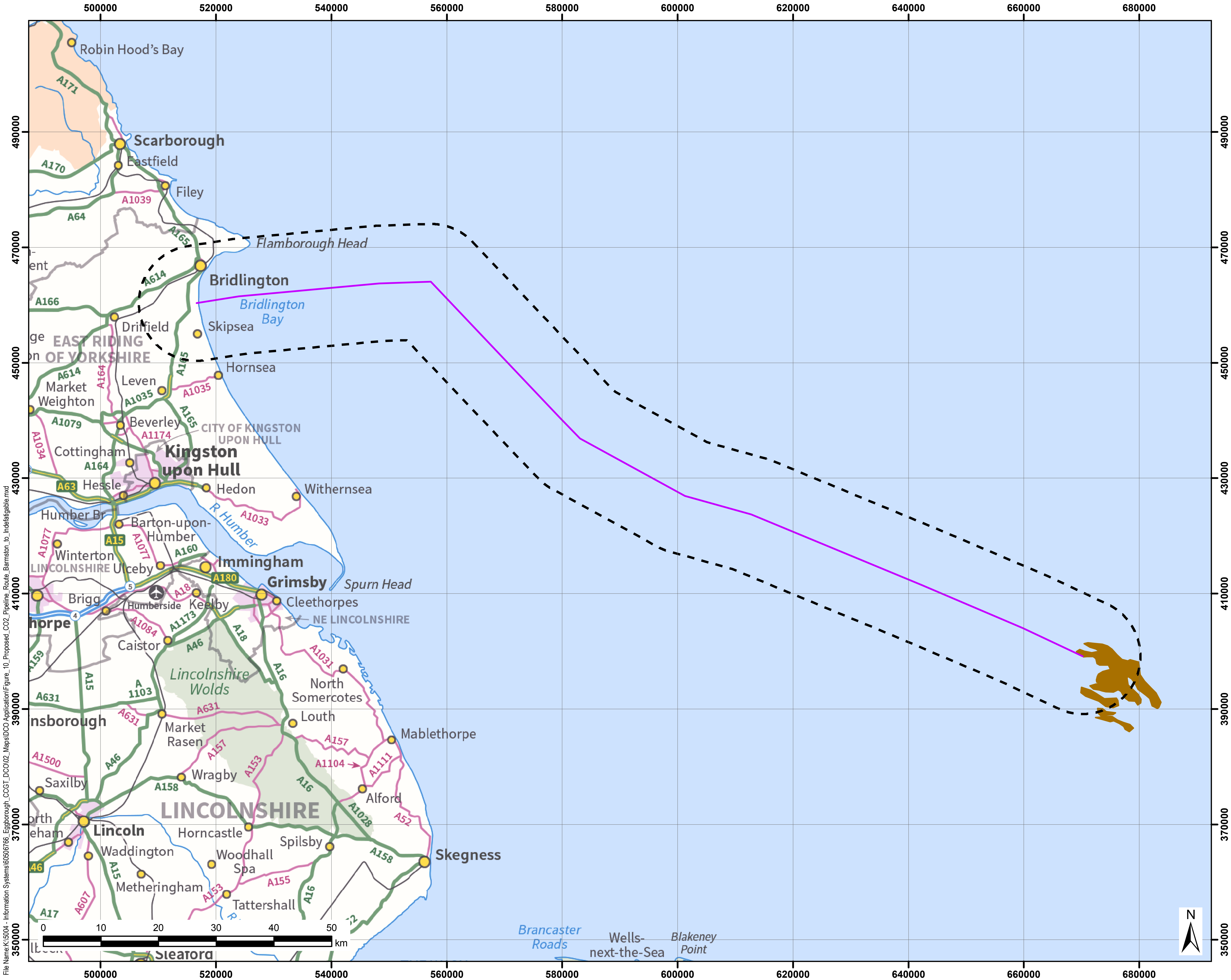
Figure 5: Indicative undersea CO_2 pipeline route - landfall to Leman Gas Field



File Name:K:\5004 - Information Systems\60506766_Eggborough_CCGT_DCO\02_Maps\DCO Application\Figure_10_Proposed_CO2_Pipeline_Route_Barmston_to_Indefatigable.mxd

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LEGEND

- Proposed CO2 Pipeline Route Barmston to Indefatigable
- 10km Offshore CO2 Pipeline Route Corridor
- Indefatigable Gas Field

British National Grid WKID: 27700

Purpose of Issue

DCO APPLICATION

Client

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Project Title

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PROPOSED CO2 PIPELINE ROUTE FROM BARMSTON TO INDEFATIGABLE

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JW	BB	JS	09/03/2017

AECOM Internal Project No.	Scale @ A3
60506766	1:600,000

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FIGURE 5

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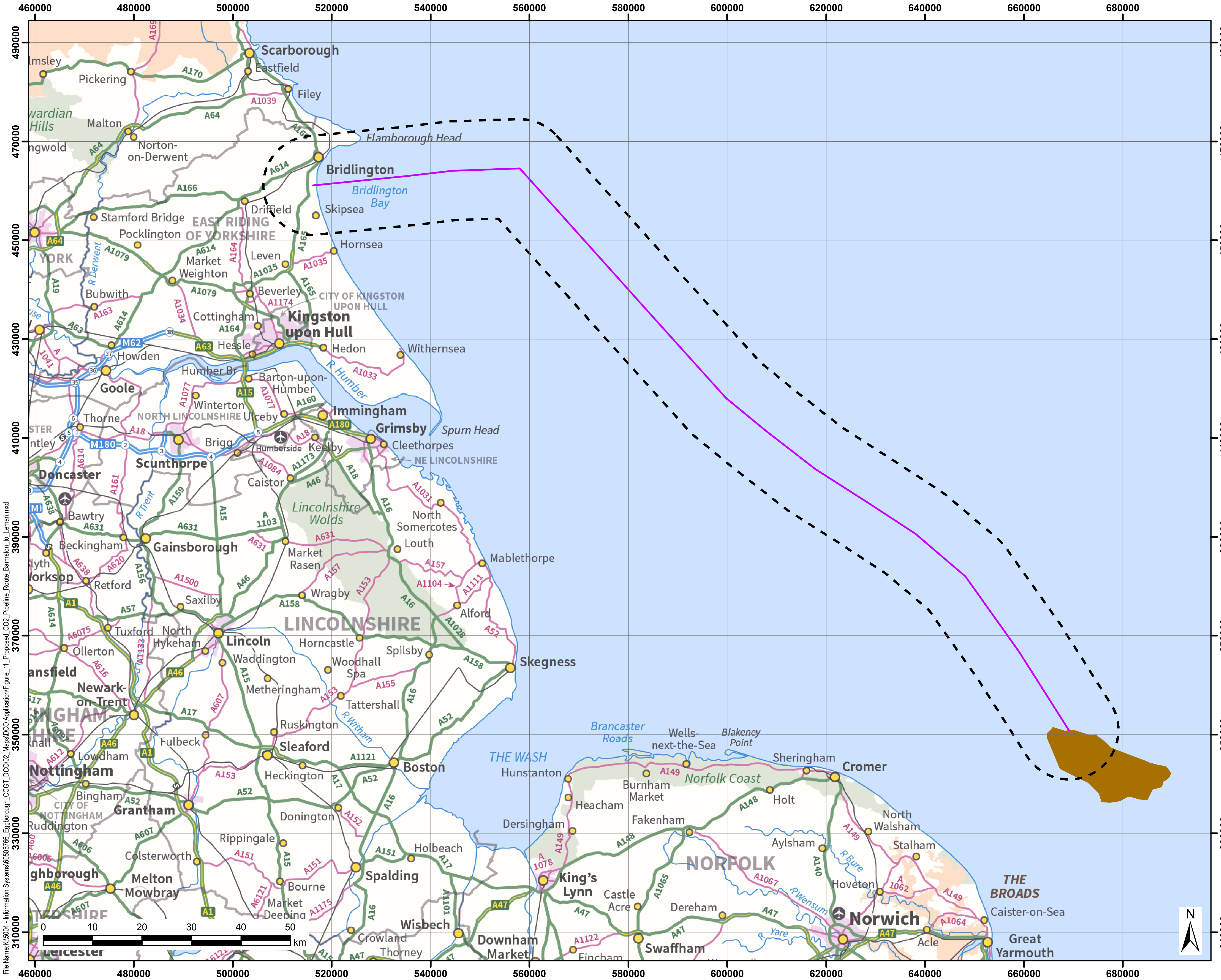
Figure 6: Indicative undersea CO_2 pipeline route – landfall to Indefatigable Gas Field



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LEGEND

- Proposed CO2 Pipeline Route Barmston to Leman
- 10km Offshore CO2 Pipeline Route Corridor
- Leman Gas Field

British National Grid WKID: 27700

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Purpose of Issue

DCO APPLICATION

Client

EGGBOROUGH POWER LTD

Project Title

EGGBOROUGH CCGT DCO

Application Document Ref

PROPOSED CO2 PIPELINE ROUTE FROM BARMSTON TO LEMAN

Drawn	Checked	Approved	Date
JW	BB	JS	09/03/2017

AECOM Internal Project No.	Scale @ A3
60506766	1:700,000

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FIGURE 6	01

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APPENDIX 1: CARBON CAPTURE TECHNOLOGY

Currently there are three types of carbon capture technology being developed, namely:

- oxy-combustion carbon capture;
- pre-combustion carbon capture; and
- post combustion carbon capture.

Each technology was considered as part of the design evolution leading to the current proposal for the Development. Each option is discussed in turn as follows.

1.1. Oxy-combustion Carbon Capture

This process involves burning fossil fuels in pure oxygen as opposed to air, resulting in a more complete combustion. This results in an exhaust stream which consists of almost pure CO_2 (typically 90%) and water vapour, which can be separated from the CO_2 by condensation.

The main problem with this method is separating oxygen from the air. This is usually completed cryogenically which requires significant energy (for a typical 500 MW power station, supplying pure oxygen requires at least 15% of the electricity the plant generates annually). In addition there is very limited knowledge regarding this technology on a commercial scale. The use of oxy-combustion carbon capture for the Proposed Development has therefore been discounted at this stage.

1.2. Pre-combustion Carbon Capture

Pre-combustion capture involves removal of CO_2, prior to combustion, to produce hydrogen. Hydrogen combustion produces no CO_2 emissions, with water vapour being the main by-product. The capture process consists of three stages; firstly the hydrocarbon fuel (typically methane, or gasified coal) is converted into hydrogen and carbon monoxide (CO) to form a synthesis gas. The second step is to convert the CO into CO_2 by reacting it with water. Finally, the CO_2 is separated from the hydrogen, which can then be combusted cleanly. The CO_2 can then be compressed into liquid and transported to a storage site.

The option of developing an Integrated Gasification Combined Cycle plant (IGCC) with pre-combustion carbon capture was discounted for the following reasons:

- this method is normally applied to coal-gasification combined cycle power plants;
- the pre-combustion method cannot easily be retro-fitted to existing power plants and an additional chemical plant is required in front of the gas turbine;
- the efficiency of H2 burning turbines is lower than conventional gas turbines; and
- the costs associated with installation of an IGCC are considerably higher than the installation of a post-combustion plant.

1.3. Post combustion Carbon Capture

In post combustion carbon capture, CO_2 can be captured from the exhaust of a combustion process by absorbing it in a suitable solvent. The absorbed CO_2 is then liberated from the solvent and is compressed for transportation and storage. Other methods for separating CO_2 include high pressure membrane filtration, adsorption/ desorption processes and cryogenic separation.

The Proposed Development comprises high efficiency, natural gas-fired CCGT units with post combustion carbon capture. The advantages of post combustion carbon capture over the other carbon capture technologies available are as follows:

- post combustion can feasibly be retrofitted to existing power stations without significant modifications to the original plant;
- post combustion is the type of technology favoured by the UK Government in its former competition to build one of the world's first commercial scale CCS power plants in the UK; and
- post combustion carbon capture technology is the most developed and closest to commercial deployment at present.

Therefore, the feasibility of CCS for the Proposed Development has been assessed on the basis of the best currently available post combustion carbon capture technology, which, for carbon capture from flue gases is using amine based solution as the CO_2 solvent. However the use of the alternative (pre-combustion or oxyfiring) technologies will not be excluded from future consideration as they may become viable at the time as and when the plant will be mandated to be retrofitted with CCS.