Great Yarmouth Power Station

Carbon Capture Readiness (CCR) Assessment

RWE Generation UK

Project number: 60648701

04th December 2023

Delivering a better world

Quality information

Prepared by	Checked by	Verified by	Approved by
Gough, Rob	Atkinson, Sam	David Menmuir	Cook, Graeme
Robert Gough Engineer	Sam Atkinson / Graeme Cook	David Menmuir Principal Engineer	Graeme Cook Associate

Revision History

Revision	Revision date	Details	Authorized	Name	Position
1	07/06/2022	First Issue		GC	Associate
2	14/07/2022	Comments addressed		GC	Associate
3	28/11/2023	S36 VO DRAFT		GC	Associate
4	04/12/2023	S36 VO FINAL		GC	Associate

Distribution List

# Hard Copies	PDF Required	Association / Company Name

Prepared for:

RWE Generation UK

Prepared by:

AECOM Limited
3rd Floor, Portwall Place
Portwall Lane
Bristol BS1 6NA
United Kingdom

T: +44 117 901 7000
aecom.com

Table of Contents

Figures

Tables

1. Introduction

1.1 Overview

This Carbon Capture Readiness (CCR) assessment has been prepared for RWE Generation UK to identify and assess decarbonisation options for the Great Yarmouth Power Station site . Amendments to this report have been made to support the Section 36C variation application being made by RWE Generation for Great Yarmouth Power Station.

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

1.2 Background

A consent under Section 36 of the Electricity Act 1989 was granted in October 23rd 1997 for Great Yarmouth power station. The original consent stated that the plant gross output was about 350MW, and a variation to increase the capacity to about 400MW was later granted on April 14th, 2001. The term 'about' is not defined within the original consent or in the subsequent variation.

The Great Yarmouth Power Station has been subject to modest improvements aimed at enhancing its efficiency flexibility, and reliability over time. Whilst these changes have resulted in small increases in capacity, the station's gross generation has remained consistent with the existing Section 36 consent under the Electricity Act of 1989. A variation of this consent is now sought to enable operation at an increased gross generation of up to 430 MWe to enable the station to operate at its maximum capacity.

The Applicant, RWE, is a leading energy supplier holding a diverse portfolio of wind, hydro, nuclear, biomass and gas electricity generating facilities, with four main operating companies in the UK, including the Applicant, RWE Generation UK plc ("RWE Generation UK"). RWE Generation UK is the owner and operator of Great Yarmouth Power Station (GYPS).

1.3 The Site

GYPS is located in Great Yarmouth, Norfolk, NR30 3PY between the River Yare and the North Sea. The subject site is accessed from the north using South Denes Road. The Grid Reference for the site is TG530050.

The site is within the administrative area of Great Yarmouth Borough Council.

1.4 The Proposed Development

GYPS is a mid-merit generation plant which delivers wholesale generation and grid balancing services. GYPS comprises one Combined Cycle Gas Turbine (CCGT) unit consisting of one single shaft GE Frame 9FA gas turbine (with Advanced Gas Path components and DLN2.6 combustion) and one D10 steam turbine.

The Proposed Development may operate continuously or at intervals during the day and night, depending on the market conditions. RWE has provided an anticipated forecast of the number of operating hours each year for the remainder of the Proposed Development's operational life with the retrofitted Carbon Capture Plant (CCP). The average number of operating hours from this forecast is approximately 4,871 hours with the CCP fully operational in 2027 and running until 2050.

1.5 Approach to demonstrating CCR compliance

The following approach has been used for this CCR assessment:

- The Proposed Development is to operate without provision of heat or steam to third party users. No CHP requirement is considered as part of this study;
- Based on a high-level conceptual design, a preferred carbon capture technology has been identified for potential future retrofit to the Proposed Development. The design of the proposed CCP is based on current Carbon Capture and Storage (CCS) technology availability;

- The sizing and utility demand of the main CCP equipment that would be required has been established using thermal and process modelling. Site layouts have been prepared to evaluate whether 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 study from the (former) Department of Trade and Industry (DTI)[1];
- Potential routes to transport the captured carbon dioxide (CO_2) from the site to the potential geological storage sites were identified, including consideration of potential use of shipping;
- An economic assessment that encompasses retrofitting carbon capture technology, transport and storage of CO_2 has been carried out for the CCP to compare the levelised cost of electricity generation (LCOE) of an abated and unabated plant with equivalent operating hours. This assessment used the prices for CO_2, natural gas and electricity stated within the Green Book supplementary guidance[2] to show whether retrofitting CCS to the Proposed Development is feasible; and
- A high-level assessment of the Health and Safety issues associated with the CCP has been undertaken.

1.6 Report Structure

This report is structured as follows:

- Section 1: Introduction;
- Section 2: Legislative Background;
- Section 3: Description of Great Yarmouth Power Station and the Proposed CCS;
- Section 4: Technical Feasibility Assessment;
- Section 5: Economic Feasibility Assessment;
- Section 6: Health and Safety Assessment;
- Section 7: Discussion of the proposed periodic review of this CCR Assessment; and
- Section 8: Conclusion

[1] Industrial Carbon Dioxide Emissions and Carbon Dioxide Storage Potential in the UK, DTI, 2006
[2] Green Book supplementary guidance, Department of Business, Energy and Industrial Strategy, 2021. Available online: https://www.gov.uk/government/publications/valuation-of-energy-use-and-greenhouse-gas-emissions-for-appraisal

2. Legislative Background

2.1 The Carbon Capture Readiness (Electricity Generating Stations) Regulations 2013

The Carbon Capture Readiness (Electricity Generating Stations) Regulations 2013 (the CCR Regulations) came into force on 25 November 2013. The UK left the EU on 31 January 2020 under the terms set out in the European Union (Withdrawal Agreement) Act 2020 ("the Withdrawal Act"). This established a transition period, which ended on 31 December 2020. The Withdrawal Act retains the body of existing EU-derived law within UK domestic law.

The CCR Regulations provide that a relevant Section 36 Consent must not be varied in such a way as to enable a combustion plant to increase its rated electrical output to 300 MWe or more (as varied), unless the appropriate 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 such carbon dioxide from the site to an appropriate long term geological storage.

The 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."*

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 CO_2 –*
>
> *a) Suitable storage sites are available;*
>
> *b) It is technically and economically feasible to retrofit the plant with the equipment necessary to capture that CO_2; and*
>
> *c) It is technically and economically feasible to transport such captured CO_2 to the storage sites referred to in sub-paragraph (a)".*

CCR Regulation 6(1) states that:

> "*The appropriate authority* [*the Secretary of State* (SoS) in England and Wales] *must not –*
>
> *b) vary a relevant Section 36 Consent in such a way as to enable a combustion plant to increase its rated electrical output*
>
> *unless the* [SoS] *has determined whether the CCR conditions are met in relation to the combustion plant, as constructed or extended in accordance with the section 36 consent as so varied ("the modified plant").*

CCR Regulation 6(3) states that where the SoS determines the CCR conditions are met and decides to vary the Section 36 Consent, the varied consent must include:

> *a condition 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."*

2.2 CCR Guidance

The UK Government's then Department for Energy and Climate Change (DECC) published guidance on CCR in November 2009 entitled "Carbon Capture Readiness (CCR) – A Guidance Note for Section 36 Electricity Act 1989 consent applications" (the "CCR Guidance"). The CCR Guidance provides relevant context for this application. Paragraph 7 of the CCR Guidance states that applicants are required to demonstrate:

- "that sufficient space is available on or near the site to accommodate carbon capture equipment in the future;
- the technical feasibility of retrofitting their chosen carbon capture technology;
- that a suitable area of deep geological storage offshore exists for the storage of captured CO_2 from the proposed power station;
- the technical feasibility of transporting the captured CO_2 to the proposed storage area;

- 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."

Paragraph 7 goes on to state that:

> *"Applicants must make clear in their CCR assessments which CCS retrofit, transport and storage technology options are considered the most suitable for their proposed development.*
>
> *In addition, if applicants' proposals for operational CCS involve the use of hazardous substances, they may be required to apply for Hazardous Substances Consent (HSC). In such circumstances, they should do so at the same time as they apply for Section 36 consent…"*

2.3 Assessment Methodology

This CCR report has therefore been prepared to fulfil the requirements of the 2013 CCR Regulations in accordance with 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 4.1 of this report. The space allocated for the CCP has been compared to the minimum footprint in the guidance (paragraphs 11 - 17 of the CCR Guidance).
- Technical Assessment of Feasibility of CCS Retrofit: Annex C of the CCR 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. It is noted that a specific checklist for the technology intended for the Proposed Development is not provided by the CCR Guidance, however, for the purposes of this CCR Assessment, Section 4.2 of this report deals with the technical response to the requirements of Annex C, as being of most relevance to the Proposed Development.
- Existence of a suitable area for the Storage of Captured CO_2: In accordance with the CCR 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 study (which is provided in Annex D of the CCR Guidance), should be proposed as suitable CO_2 storage locations for the Proposed Development. Such sites are identified in Section 4.3 of this report.
- Technical Feasibility of Transport of Captured CO_2: The CCR 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 (paragraphs 43 to 61 of the CCR Guidance). The technical feasibility of transporting the captured CO_2 to the storage area proposed for the Proposed Development is assessed in Section 4.4 of this report, noting that at the time of drafting the 2009 guidance, the use of carbon capture clusters was not considered to be reliable, whereas recent policy changes now actively support and encourage the use of clusters for the development and operation of carbon dioxide transport and storage networks. In November 2020, the Ten Point Plan for a Green Industrial Revolution[3] stated a commitment to deploy CCUS in two industrial clusters by the mid-2020s and a further two clusters by 2030.
- Economic Assessment of the Feasibility of CCS: The CCR Guidance states that the main aim of the economic assessment is to provide an indication of the future likelihood of a retrofit of CCP equipment, CO_2 transport and storage of CO_2 being economically feasible at some stage during the Proposed Development's operational lifetime (paragraphs 62 – 69 of the CCR Guidance). This is developed in Section 5 of this report.
- Health and Safety Analysis: An analysis of Health and Safety issues associated with the CCP including consideration of whether a Hazardous Substances Consent may be required for the CCP proposed for the Proposed Development is provided in Section 6 of this report (paragraphs 70 - 82 in CCR Guidance).

It should be noted that pre-combustion techniques may lead to similar, or smaller, space requirements and have the potential to reduce or avoid the need for CO_2 transport by the 'upstream' removal of CO_2 from the fuel before combustion. This assessment is therefore a worst-case approach in terms of assessing the space requirements for CO_2 capture/ removal.

[3]The Ten Point Plan for a Green Industrial Revolution, HM Government, 2020. Available online: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/936567/10_POINT_PLAN_BOOKLET.pdf

3. The Proposed Development and Potential CCS

3.1 Location

GYPS is located in the south of Great Yarmouth, Norfolk, NR30 3PY between the River Yare and the North Sea (the "Site"). The land is within RWE Generation UK ownership as shown in Figure 3-1 and is located on South Denes Road. The area considered for the proposed Carbon Capture Plant (CCP) is within the existing GYPS plot on the northeast corner of the site.

Figure 3-1 RWE Generation UK land holding boundary of Great Yarmouth Power Station[4]

Gorleston-on-Sea is approximately 300m west of the Site and Great Yarmouth is approximately 750m north of the Site. There are several business units in the adjacent land to the north of the Site.

There are some Scheduled Monuments near to the Site including the Burgh Castle (approximately 5km west).

3.2 Plant Description

GYPS is a mid-merit generation plant which delivers wholesale generation and grid balancing services. GYPS comprises one CCGT unit consisting of one GE 9FA gas turbine and one steam turbine. The Proposed Development retains the same plant configuration and will permit the future operation of GYPS. The power station may operate continuously or at intervals during the day and night, depending on the power demand requirements of the National Grid. The estimated average annual operating time of the gas turbine is approximately 4,871 hours based on RWE's forecast of operating hours for the remainder of the power station's operational life.

The condenser is cooled through a once through cooling system with water abstracted from the River Yare and discharged into the North Sea.

The anticipated remaining operational lifetime of the power station, if carbon capture were to be retrofitted, is at least 24 years from 2027. The precise closure date of the power station will depend on operational and market conditions.

[4] Screenshot taken courtesy of Google Earth

3.3 Proposed Carbon Capture and Storage Technology

The current regulatory position is that the CCP 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 electricity generating stations is set at a level (450 gCO_2/kWh)[5]. This EPS is proposed by UK Government to be maintained for consented plants until and including 2044.

There are three alternative carbon capture technologies available, namely:

- Pre-combustion carbon capture;
- Post combustion carbon capture; and
- Oxy-combustion carbon capture.

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

As any CCS would have to be retrofitted to the Proposed Development 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 for retrofitting to the Proposed Development during its operational life and the pre-combustion alternative option has not been developed for gas power generation in the UK.

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, would use an amine-based solution as the absorption medium. RWE Generation UK will keep under review the various pre- and post-combustion options.

3.3.1 Process Design Basis

The conceptual design has been based upon the post-combustion modelling developed using the Thermoflow process modelling software (Thermoflex29), using heat cycle and flue gas composition data provided by the Applicant for the Site. In common with studies for other generating stations, a 95% CO_2 capture efficiency has been used as the basis.

This CCR assessment assumes that a capture efficiency of 95% is adopted since this represents the baseline target for CCS and will give a suitable CCP area, net thermal efficiency reduction and storage reservoir requirement.

GYPS is known to utilise the majority of its existing abstraction levels from the River Yare, and an increase in abstraction volumes may not be granted. Air cooling for the CCP would require additional area compared to hybrid cooling, and sufficient area is not available. The project's intention is to develop additional water supplies to allow for a hybrid cooling solution for the CCP heat rejection in accordance with BAT hierarchy.

This study has been developed for a single carbon capture train processing the entire mass flow rate of flue gas from the gas turbine.

Potential operational issues related to implementation of flexible CCS cycles can be addressed using one of the techniques discussed in the BEIS study published in 2020[6]. These techniques may include developed rich and lean amine inventory management and using stored heat to pre-heat the regenerator column.

[5] Energy Act 2013 (c.32), Part 2 Electricity Market Reform, Chapter 8 – Emissions performance standard
[6] Start-up and Shut-down times of power CCUS facilities, AECOM study for the Department of Business, Energy & Industrial Strategy, May 2020. Available online: https://www.gov.uk/government/publications/start-up-and-shut-down-times-of-power-carbon-capture-usage-and-storage-ccus-facilities

4. Technical Assessment

4.1 Space

4.1.1 Footprint Estimate

At this stage, the final design of any potential CCP and equipment has not been developed and none would be undertaken until CCS was mandated to be required for the Site. Therefore, for the purposes of this CCR Assessment, a 'worst case' concept design and footprint area calculation has been estimated using the following sources of information:

- DECC CCR Guidance[7];
- Imperial College Paper on CCS Footprint Review[8]; and
- AECOM databases on CCP design from several CCGT retrofit concept and gas reciprocating projects.

On this basis the indicative 'worst case' total footprint has been estimated based on the calculations of one train of CCP 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.

Note that the Direct Contact Cooler (DCC), Absorber, Wash Water and Stripper columns footprint have been treated as square with the sides equal to column hydraulic diameter to allow for adequate space provision as well as the Lean Amine Storage Tank.

Table 4-1 CCP equipment list and area per train

Equipment	Number of Pieces	Length / m	Width / m	Footprint Area / m^2
Flue Gas Booster Blower	3	8.7	4.3	113.1
DCC Column	1	15.5	15.5	239.2
DCC Filter Pump	2	1.5	1.5	4.5
DCC Circulating Water Cooler	1	2.1	8.1	17.3
DCC Circulating Water Pump	2	2.2	2.2	9.7
DCC Circulating Water Filter	2	0.5	0.5	0.5
Solvent Make-up Pump	2	1.0	1.0	2.0
Rich Solvent Pump	2	3.5	2.5	17.5
Lean Solvent Pump	2	3.5	2.5	17.5
Wash Water Circulating Pump	2	1.5	1.5	4.5
Reflux Pump	2	1.5	1.5	4.5
Condensate to Deaerator Pump	2	2.0	2.0	8.0
HCT Recirculation Pump	2	2.0	2.0	8.0
Waste Water Sump Pump	2	1.0	1.0	2.0
Solvent Sump Pump	2	1.5	1.5	4.5
H_2SO_4 Solution Pump	2	1.5	1.5	4.5
NaOH Solution Pump	2	1.5	1.5	4.5
Wash Water Cooler	1	3.2	4.6	14.9
Solvent Cross Exchanger	1	19.3	8.1	155.8
Lean Amine Cooler	1	3.2	4.6	14.9
Reclaimer	1	7.8	15.8	123.9

[7] Carbon Capture Readiness (CCR) – A guidance note for Section 36 Electricity Act 1989 consent application, Department of Energy & Climate Change, November 2009. Available online: https://www.gov.uk/government/publications/carbon-capture-readiness-ccr-a-guide-on-consent-applications

[8] Assessment of the validity of ―Approximate minimum land footprint for some types of CO_2 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

Stripper Condenser	1	16.1	7.0	112.6
Hybrid Coolers	1	93.9	13.6	1277.6
Stripper Reboiler	1	38.7	14.1	544.4
Lean Amine Storage Tank	1	15.7	15.7	246.1
Fresh Amine Storage Tank	1	3.5	10.5	37.3
Overhead Accumulator	1	2.1	2.1	4.4
H_2SO_4 Solution Tank	1	1.4	1.4	2.0
NaOH Solution Tank	1	1.4	1.4	2.0
Absorber Column 1 (Note 1)	1	14.7	14.7	214.7
Absorber Column 2 (Note 1)	1	14.7	14.7	214.7
Wash Water Column (Note 1)	1	14.7	14.7	214.7
Stripper Column	1	8.1	8.1	66.3
Wash Water Filter	2	0.5	0.5	0.5
Lean Solvent Filter	2	7.0	4.2	58.8
Solvent Sump Filter	2	0.5	0.5	0.5
Waste Water Sump Filter	2	0.5	0.5	0.5
Activated Carbon Filter	2	4.5	4.5	40.5
Compressor Stages Enclosure	1	23.6	19.7	464.8
CO_2 Dehydration Unit	1	16.5	18.9	312.9
CO_2 Deoxygenation Unit	1	2.4	2.4	5.6
CO_2 Product Metering Package	1	3.1	9.5	29.5
Antifoam System	1	6.0	6.0	36.0
Instrument Air System	1	8.0	8.0	64.0
Nitrogen Blanketing System	1	5.0	5.0	25.0
Water Treatment Plant	1	8.0	12.0	96.0
Demin Water Plant	1	8.0	12.0	96.0
CCS Plant Subtotal				4938.3
Duct Work to Blowers (subject to layout)	1	56.3	5.7	321.1
Duct Work to Absorber Column 1	1	5.0	5.7	28.5
Duct Work to Absorber Column 2	1	15.0	5.7	85.5
Duct Work to Wash Water Column	1	15.0	5.7	85.5
Duct Work Subtotal				520.7
		Total per CCP train including duct work		5,459
Note 1: Absorber columns 1 and 2 and the Wash Water Column may be combined into one column. The total area required will be similar.		Total per train including a margin of 3.0 applied to the CCP to allow for O&M access and the required spacing around hybrid coolers, and 1.5 applied to the duct work		15,596
		Total for plant (1 train)		15,596
		CO_2 capture footprint required m^2/MW (calculated based on outline design and 430MW gross plant capacity)		36.3

4.1.2 Footprint Comparison

Table 1 in the 2009 CCR Guidance provides an indicative CCR space requirement based on a 500MWe (net) power plant. For a CCGT power plant with post-combustion carbon capture, the indicative CCR space requirement was initially provided at 3.75ha for 500MWe (net), which equates to 75m^2/MWe (net).

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 2.4ha for 500 MWe (net). This equates to 48m^2/MWe (net).

In addition, the review by Imperial College further detailed additional scope for a reduction in the indicative CCS space requirement by 50% to 1.875ha (including the reduction of 36%) considering technology advances and layout optimisation. This equates to 37.5 m^2/MWe (net). However, the paper also states that such a reduction can only be justified following a detailed engineering design rather than only a linear scaling of this value.

AECOM has calculated an estimated carbon capture site area of circa 15,596 m^2 (36.3m^2/MW) from the indicative CCP component design shown in Table 4.1. This figure is below the specific area target of 37.5m^2/MW. For the purposes of this assessment a minimum area requirement figure of the order of 16,200m^2 has been assumed (37.5m^2/MW * 430MW gross). The nominal gross electrical output of 430MW has been used in this sizing calculation. Note that 430MW gross is equivalent to 420MW net due to an approximate parasitic load of 9MW of the unabated plant.

This available land is split across three discrete plots within the northwest corner of the current site separated by the existing site road. As a result, the footprint within the plant layout is greater than the estimated value from Table 4-1 as large items (such as the hybrid cooling towers) may need to be separated. Appendix A shows the indicative plant layout for the CCP occupying 16,200 m^2 within the space allocated on site for CCR purposes. This preliminary layout has scope for minor optimisations such as the positioning of the stripper and compressor.

Based on the site layout drawing contained in Appendix E at least 7000m2 of additional land outside of the site boundary would be required for construction of the CCP. Additional land would be required during construction for equipment laydown. The availability of sufficient space is a barrier to demonstrating the technical feasibility of retrofitting CO2 capture equipment at this site.

4.2 Retrofit

4.2.1 Introduction

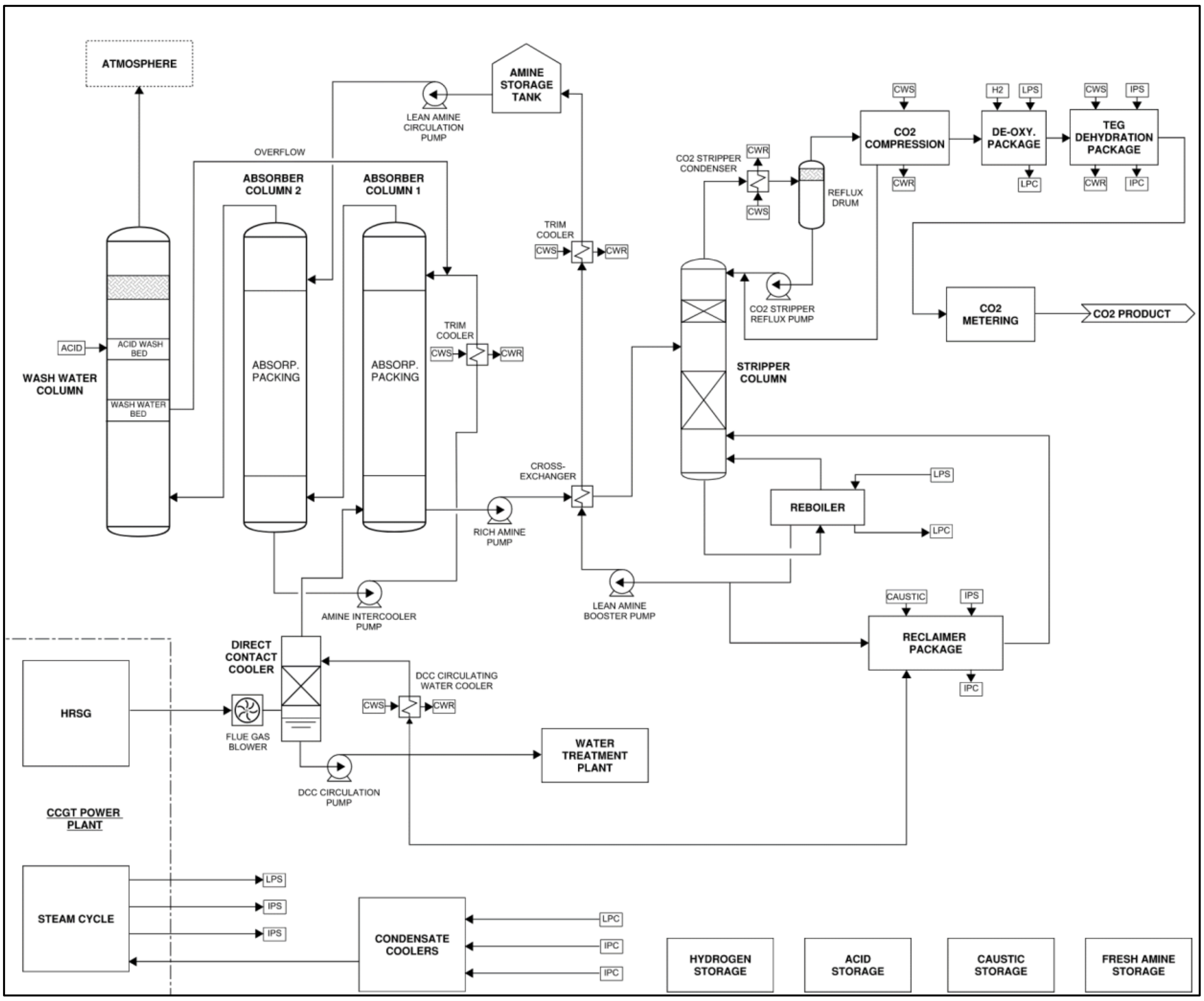
The technical feasibility to retrofit carbon capture equipment in the future to the Proposed Development has been assessed against the criteria presented in Annex C of the DECC CCR guidance note[9]. The design point at reference ambient conditions and a maximum power output of 430MWe gross has been used to determine the heat and material balance data assumed in this report.

4.2.2 Design, Planning Permissions and Approvals

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. RWE Generation UK will keep under review the various pre- and post-combustion options. An outline level plot for the plant is provided in Appendix A with the simplified block flow diagram presented in Figure 4-1 to show an overview of the process within the CCP.

[9] Carbon Capture Readiness (CCR) – A guidance note for Section 36 Electricity Act 1989 consent application, Department of Energy & Climate Change, November 2009. Available online: https://www.gov.uk/government/publications/carbon-capture-readiness-ccr-a-guide-on-consent-applications

Figure 4-1 CCP process block flow diagram



4.2.3 Power Plant and Capture Plant Location

As shown in Appendix E, there are three plots of land required for the CCS technology and balance of plant equipment. These have been laid out in an area to the north of the HRSG building, which utilise as much available space within the site boundary as possible. However, 7000m^2 of the area required for the Carbon Capture Plant (shown in light blue) is unavailable as it is currently used for parking, storage and laydown for the existing facilities. This is a barrier to technical feasibility for carbon capture as there is insufficient available area within the site boundary for construction of the CCP.

It is anticipated that the exit point for the captured CO_2 from the Proposed Development will be located to the east of the Site. The final location will be selected depending on the agreed method and route of CO_2 transportation, but will remain within the relevant area, as shown in Appendix A.

Where appropriate, pipe racks 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 0.15m assuming an allowable velocity of 3.5m/s.

Further information on the transport and storage of captured CO_2 off-site is provided in Sections 4.3 and 4.4.

4.2.4 Space Requirements

The footprint presented in Section 4.1 of this report was used to prepare the plot plan presented in Appendix A 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;

- Any extensions or additions to the balance of plant on the gas turbine units where necessary to cater for the additional requirements of the capture equipment;
- Maintenance 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.

Total lifetime CO_2 emissions were based upon a single gas turbine with 636 kg/s, 6.52% CO_2 by mass with a 95% capture efficiency for 4,871 hours per annum over 24 years. Major equipment sizes have been scaled on mass flow of CO_2 captured from similar benchmark studies.

To the extent possible, existing roadways within the site boundary are to be retained. An overall margin has been added to total equipment area to allow conservative provision for additional maintenance access and roadways providing sufficient space for these features.

The CCP has been designed around steady state conditions, however flexible start up and shut down CCS evaluations show that the space requirements are comparable, and they are achievable for this plant within the overall margin discussed above.

In terms of the land required for laydown during construction of the CCP, the laydown area would be determined and secured nearer the time of installation. The Applicant estimates that approximately up to 20,963 m^2 of land for future laydown would be potentially required based on ~30% margin above the required plant area (total plant footprint 15,750 m^2 x 1.3). This would be developed further in a detailed Construction Management Plan as part of the EPC Contractor's procurement and site management responsibility. It is envisaged that temporarily leased land would be used for laydown purposes. There is an adjacent plot of ~ 24,200 m^2 which represents sufficient land in the locality of the Site to be used for laydown.

4.2.5 Gas Turbine Operation

The gas turbines may be unable to accommodate the increased backpressure due to the addition of CCS trains. Therefore, the design for the CCP includes a booster fan/blower to compensate for the pressure drop through the CCP (primarily in the absorbers, direct contact cooler and dampers).

Based on the flue gas flow rate of around 636 kg/s from the power plant with a nominal pressure rise of 90 mbar, a booster fan with a power rating of approximately 8.7 MWe for the single CCS train has been included in the CCP power requirement.

As and when the CCP is designed in detail, detailed specifications for this fan will be developed. These would include provisions for the pressure 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 CCP; there is an adequate provision on the CCP for its installation.

4.2.6 Flue Gas System

The flue gas system has been developed based upon current studies for CCGT post-combustion capture and includes similar design elements. The following subsections describing the flue gas system proposed for the CCP. The current layout is not optimised and consideration for a better site utilisation between the combined cycle generating plant and the CCP could be made at a later stage.

4.2.6.1 Isolation and Bypass Dampers

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

This arrangement allows for the CCP 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 plant 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. The location of the isolation and bypass damper with respect to the steam raising plant will be determined in future studies.

4.2.6.2 Flue Gas Cooling

The absorption process requires a flue gas cooler to lower the flue gas temperature to around 45-55°C to enhance the CO_2 chemical absorption and to minimise amine degradation. The flue gas is routed 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 directed to a wastewater treatment plant. Flue gas from the HRSG is pressurised in the Flue Gas Blower before entering into the DCC. Pressurisation is required to overcome the frictional losses in the ducting, Gas to Gas Heat (GGH) Exchangers, DCC and Absorber columns.

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. The heat exchanger has not been sized for this study but could be considered, if required, during detailed design.

4.2.6.3 CO_2 Absorbers

To help minimise the height of the CCP below the current stack height of GYPS (70m), the CO_2 Absorber column has been split into three separate, shorter columns: two Absorber columns and one Wash Water column as shown in Figure 4-1.

After being quenched to the correct temperature, the flue gas from the DDC enters the 1st CO_2 Absorber column at the lowest section of packing. Semi-lean amine solution from the intercooler enters the column at the top of the packing at approximately 40°C and counter-currently contacts the flue gas which is travelling upwards. This results in the absorption of CO_2 into the liquid phase as a temporary salt product via the acid-base reaction between dissolved CO_2 and monoethanolamine (MEA). Amine rich in the CO_2 drops into the Absorber sump whilst treated flue gas rises and exits the column where it then enters the sump of the 2nd Absorber column.

The 2nd Absorber column provides further contact between the partially treated flue gas travelling upwards; and lean amine supplied to the top of the packed section which travels downwards and collects in the 2nd Absorber column sump. The 2nd Absorber column sump gathers the semi-lean amine solution which is pumped through the intercooler into the top section of the 1st Absorber column. Following the 2nd Absorber column, flue gas enters the Wash Water column. Note that CCGT flue gas may not require intercooling, in which case the intercooler would be either manually bypassed or not fitted for a CCGT application. Rich amine then leaves the bottom of the 1st Absorber column and is transferred to the Stripper by the Rich Solvent Pump.

The Wash Water column contains two wash beds for recovery of contaminants from the treated flue gas, comprising:

- A single water wash bed which circulates water to cool the flue gas that enters from the amine absorption column, condensing volatile compounds within the flue gas to minimise solvent wastage by returning the volatile solvent to the circulation loop.
- A second wash bed circulating with concentrated sulphuric acid to capture contaminants such as ammonia from the treated flue gas to ensure air emissions controls are met.

Prior to being discharged to the atmosphere, the flue gas is passed through a mist eliminator device to recover any mist or droplets from the flue gas. Following the mist eliminator, the flue gas enters the stack and emissions monitoring equipment for discharge to atmosphere. No evaluation of the potential frequency of visible plumes from the final flue gas discharge from the CCP has been undertaken at this stage. This will be evaluated at the detailed design stage and if required appropriate mitigation – such as stack reheat – would be considered.

4.2.6.4 CO_2 Stripper

Rich solvent leaves the bottom of the 1st Absorber column 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.

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.

4.2.6.5 Stripper Overhead Condenser

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

4.2.6.6 Amine Reclaimer

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 such 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 feed the reactions and processes required to allow for the recovery of part of the degraded amine-based solvent. The reclaimer is expected to operate on an intermittent basis when the content of dissolved salts exceeds a predefined value.

4.2.6.7 Centrifugal Compressor

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. For the purposes of this study, the delivery pressure for the captured CO_2 is assumed to be 151 bara.

4.2.6.8 Dehydration Unit

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

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 the critical point for CO_2.

4.2.7 Steam Cycle

A supply of 65.3 kg/s of low pressure (3.4 bara) steam at 158°C (143 MW heat) per train is required for the amine regeneration process. The steam supply is integrated with the existing CCGT plant. The retrofit would involve additional piping and dampers at the tie-in point, together with appropriate metering and instrumentation and control system modifications.

Steam requirements have been modelled based on an integrated steam cycle from the existing plant. The steam demand has been based on typical requirements based on MEA solvent as a conservative assumption; proprietary solvents from licensors would typically lower the steam demand since their energy performance has been optimised.

4.2.8 Cooling System

The amine-based CCS process has a considerable cooling duty, which is estimated at 227 MWth based on Thermoflow model for the single train. The mass flow rate of cooling water is approximately 5,900 kg/s with an inlet and outlet temperature of 40°C and 30°C respectively based on a summer design conditions. 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.

The Site currently uses the majority of its abstraction licence allowance from the River Yare. Air cooling for the CCP will require an additional area of circa 7,000 m^2 compared to hybrid cooling, and sufficient area is not readily available. The intention is to develop additional water supplies to allow for a hybrid cooling solution in accordance with BAT hierarchy. Therefore, it is proposed for the basis of this study that the CCP uses a hybrid cooling system with the need to revisit abstraction requirements in future. The illustrative site layout in Appendix A includes provisions for hybrid coolers. Sizing calculations have assumed a higher ambient temperature of 25°C to conservatively determine the space provision required.

Once through cooling could also be considered in future project phases, although this would require even more water abstraction than a hybrid cooling system. The final selection of cooling technology would be in a future detailed engineering stage for the CCP.

4.2.9 Compressed Air System

There is no requirement within a standard amine-based CCP for any compressed air for process purposes, but only for the supply of instrument air and general service air to the CCP. This requirement shall be determined 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 Proposed Development, or by installing a new dedicated system for the CCP.

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

4.2.10 Water Treatment

4.2.10.1 Raw Water

The CCP will have a make-up raw water demand of approximately 101 kg/s. This water shall make up for evaporative losses within the hybrid cooling towers as well as the small losses in the amine/water solution loop caused by amine degradation or carry over.

It is assumed that sufficient headroom remains within the existing site abstraction license to accommodate the water demand for the CCP. The level of water treatment necessary for the CCP, including filtration and chemical dosing, will depend on the water quality at the abstraction site.

4.2.10.2 Demineralised Water

At present this is estimated to be approximately 13.1 kg/s peak as per Fluor's Econoamine FG process, although there are studies[10] which suggest that demineralised water quality is not required for the amine solution make-up water and only good quality water is required. Should demineralised water quality be required, there is sufficient space in the proposed layout to include a dedicated water treatment plant which is estimated to have a footprint of around 8m x 12m.

4.2.10.3 Wastewater

The detailed design of the CCP will include appropriate surface water drainage systems including oil interceptors as necessary, 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 footprint allocation for each piece of equipment.

Wastewater 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 34.2 kg/s. Table 4-2 lists the wastewater treatment requirements.

Table 4-2 Wastewater Output (per train)

Parameter	Value
Drain Water from CO_2 compression CCP (kg/s)	0.6
DCC blowdown (kg/s)	6.8
Drain Water from Knockout drum (kg/s)	6.6
Hybrid CT blowdown (kg/s)	20.3

Source: AECOM

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

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

[10] IEA Greenhouse Gas R&D Programme (IEA GHG), "CO_2 capture ready plants", 2007/4, May 2007. Available online: https://ieaghg.org/docs/General_Docs/Reports/2007-4%20Capture%20Ready.pdf

volume effluent stream which it is envisaged will be directed to the on-site effluent treatment plant, subject to assessment of ammonia levels.

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 0.08kg 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.

It is proposed that the detailed design stage for the CCP includes an assessment of whether it is appropriate to combine the condensed water stream with the wastewater stream. Combining the streams may reduce the amount of neutralisation required at the wastewater treatment plant as the DCC drain will be slightly caustic, while the condensate drain will be slightly acidic. The detailed design would also identify whether any modifications to any existing effluent treatment system were required at that time.

4.2.11 Electrical

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.

The total power requirement of the CCP is approximately 27.0 MW. Further detail of individual users is presented in Table 4.3.

Table 4-3 CCS Electrical Power Consumption (per train)

CCS Equipment Item(s)	Estimated Electrical Consumption (MW)
CO_2 compressor	13.7
Solvent recirculation pumps	1.3
Booster fan	8.7
Hybrid cooling tower fans	1.1
Cooling water circulation pumps	0.7
DCC water pump	1.1
Miscellaneous	0.4
Total	**27.0**

Source: AECOM

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

4.2.12 Pipework

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

4.2.13 Control and Instrumentation

The control and instrumentation system for the CCP 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 CCP for standalone control equipment should this be required.

4.2.14 Plant Infrastructure

It is anticipated that major plant may be delivered by road. There are not considered to be any access constraints that could impede any future construction activities.

The provision of space for additional plant infrastructure is illustrated in the illustrative site layout in Appendix A.

The final provisions for plant infrastructure will be detailed in the final design of the CCP.

4.3 CO_2 Storage

The maximum theoretical volume of CO_2 anticipated to be captured during the lifetime of the Proposed Development is 16.4 million tonnes (assuming approximately 140 tCO_2/hour from the plant units, an average of 4,871 operating hours per year and an estimated 24 years of post-abatement).

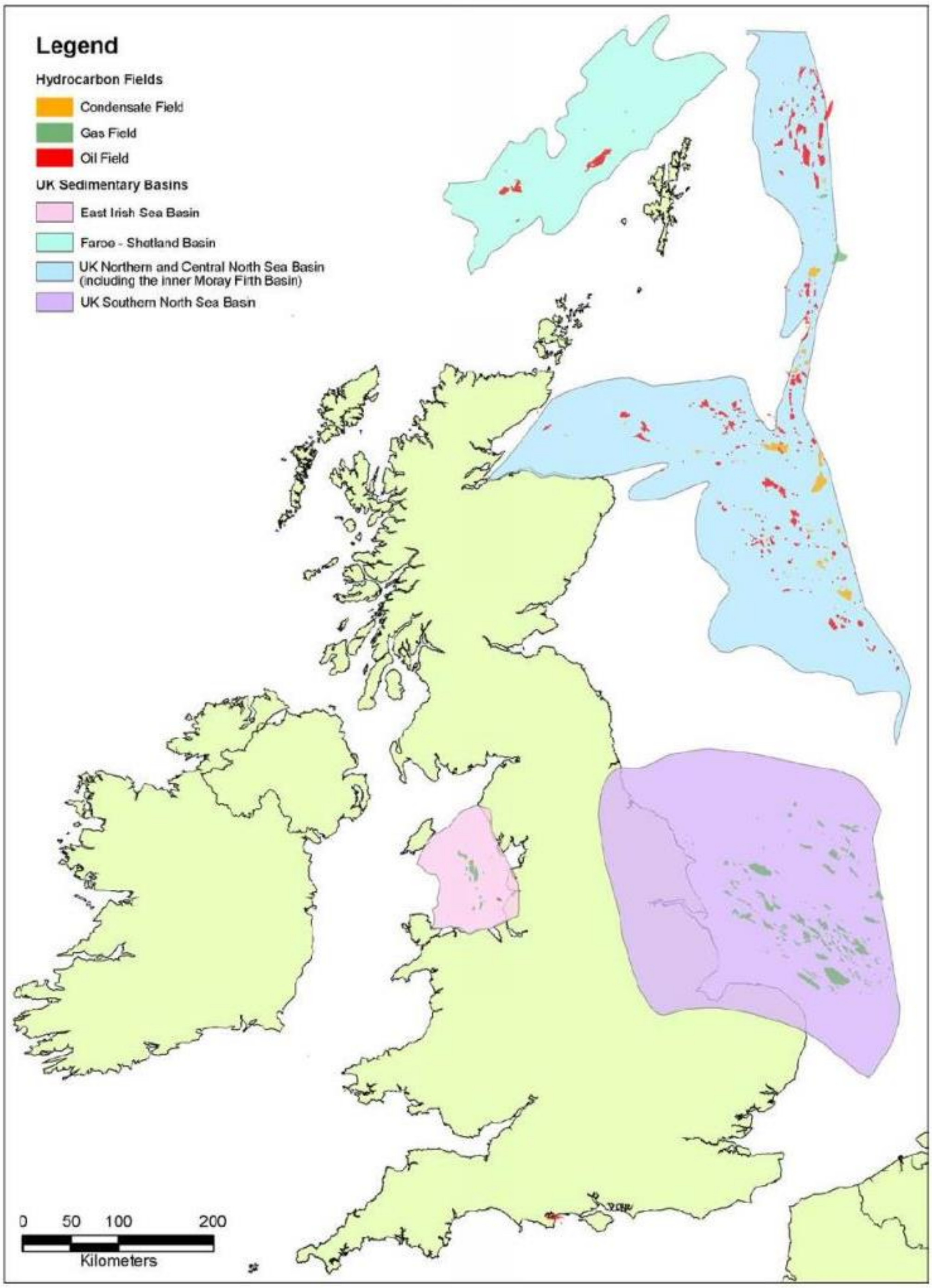
The UK's major potential sites for the long-term geological storage of CO_2 are offshore depleted hydrocarbon (oil and gas) fields and offshore saline water-bearing reservoir rocks / aquifers.

Oil and gas fields 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.

As shown in Figure 4.1 most of the UK's large offshore oil fields are mainly in the Northern and Central North Sea Basin. The UK's offshore gas fields occur mainly in two areas: the Southern North Sea Basin and the East Irish Sea (EIS) Basin. 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.

Figure 4-2 Location of offshore hydrocarbon fields and hydrocarbon bearing basins[11]



The Proposed Development is located in Norfolk, therefore the nearest hydrocarbon fields to the Site are located in the Southern North Sea (SNS) Basin.

Based on the DTI Study 2006, due to their location and capacity the following gas fields within the SNS Basin are considered potential storage areas for the CO_2 captured from the Proposed Development:

- Hewitt (L & U) Bunter Gas Fields;
- West Sole Gas Field;
- Barque Gas Field.

[11] (British Geological Survey (BGS) (October 2006) Industrial Carbon Dioxide Emissions and Carbon Dioxide Storage Potential in the UK (DTI/Pub URN 06/2027), prepared or the UK Department of Trade and Industry, now the Department of Business Enterprise and Regulatory Reform.)

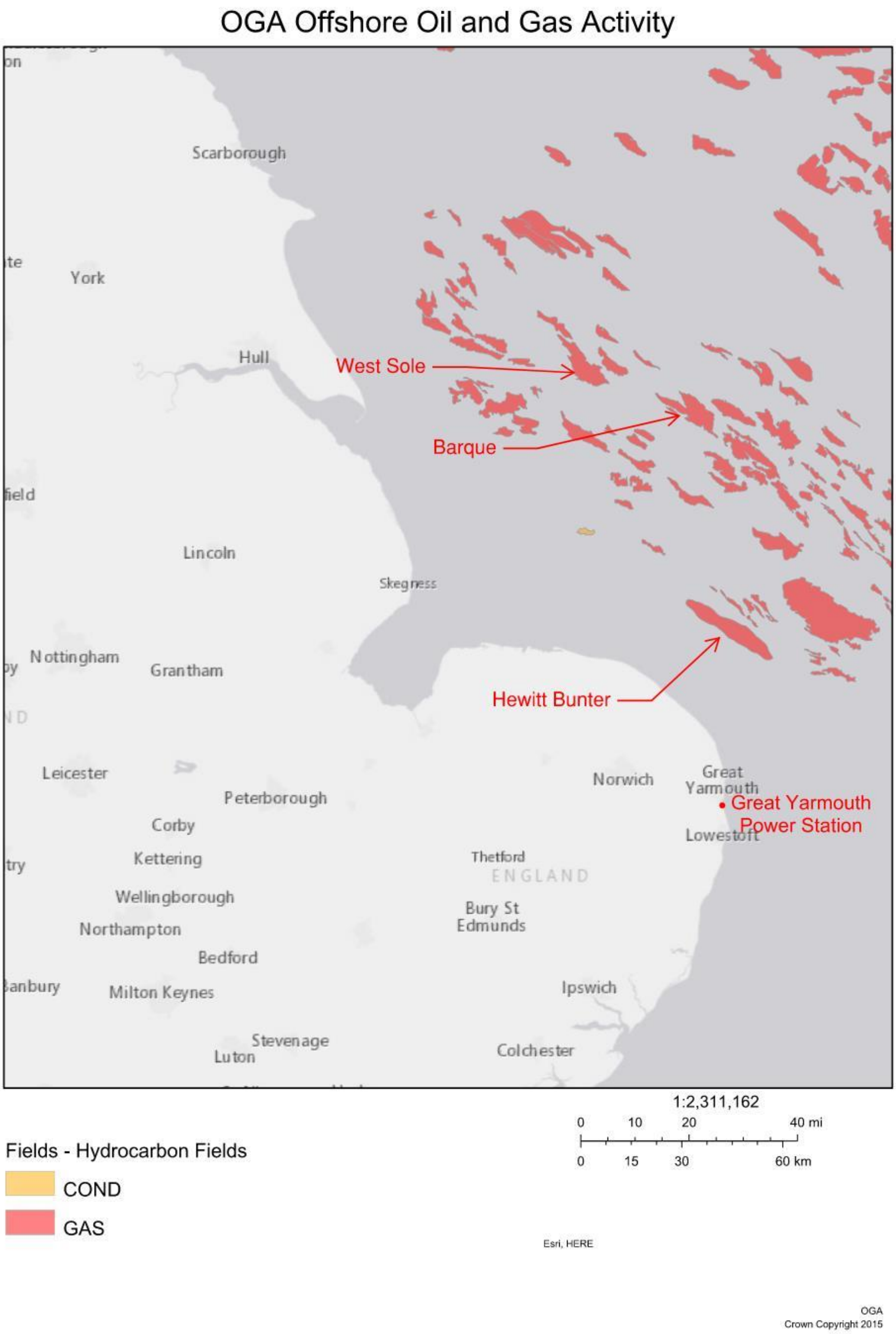
Based on the total storage requirements of the Proposed Development, Table 4-4 illustrates the percentage storage requirements on these three gas fields.

Table 4-4 Capacity of proposed geological storage areas

Field Name	Total Volume of CO_2 emitted by Proposed Development / MT	Capacity of Geographical Storage Area / MT	% of capacity
Hewitt (L&U) Bunter Gas Fields	16.4	359	4.6
West Sole Gas Field	16.4	143	11.5
Barque Gas Field	16.4	108	15.2

The location of these storage areas are illustrated on Figure 4.2 below.

Figure 4-3 Location of offshore hydrocarbon fields in the SNS Basin[12]



In accordance with the DECC guidance, the gas fields listed above are identified as 'realistic' storage locations in the DTI report (British Geological Survey (BGS) (October 2006) Industrial Carbon Dioxide Emissions and Carbon Dioxide Storage Potential in the UK (DTI/Pub URN 06/2027), prepared for the UK Department of Trade and Industry, now the Department of Business, Energy & Industrial Strategy.

[12] Offshore Oil and Gas Activity (Mapping Applications), Oil & Gas Authority, Available online: https://ogauthority.maps.arcgis.com/apps/webappviewer/index.html?id=adbe5a796f5c41c68fc762ea137a682e

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.”

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. According to the UK Government Website[13], the three largest gas fields considered above have existing potential consented users. The consented users and their requirements for the relevant gas fields are summarised in Table 4-5.

Table 4-5 Potential usage of SNS gas fields based on CCR reports received by BEIS

Field Name	Consented User	Requirement of Consent User / MT
Hewitt (L&U) Bunter Gas Fields	Damhead Creek	84
	Willington C	200
	Gateway Energy Centre	74
West Sole Gas Field	Spalding Energy Expansion	78
Barque Gas Field	Thorpe Marsh CCGT	69

This gives a currently consented total of 359Mt within the Hewitt Bunter Gas Field which only leaves a remaining CO_2 storage capacity of 1Mt. For this reason, the Hewitt Bunter Gas Field is not considered any further within this study due to the lack of remaining storage capacity. The remaining CO_2 storage capacity within the West Sole and Barque Gas Field will be 65Mt and 39Mt respectively as shown in Table 4-6.

Table 4-6 Potential capacity utilised for proposed geological storage areas

Field Name	Capacity of Geographical Storage Area / MT	Total Volume of CO_2 emitted by Other Consent Users / MT	Remaining capacity of Geographical Storage Area / MT	Total Volume of CO_2 emitted by Proposed Development / MT	% of capacity
West Sole Gas Field	143	78	65	16.4	25.2
Barque Gas Field	108	69	39	16.4	50.3

The West Sole and Barque Gas Fields are both considered suitable storage location sites for this project due to their considerable available capacity. The Barque Gas Field will require a slightly shorter offshore pipeline compared to West Sole, and therefore is proposed as the chosen storage site for the Proposed Development.

The storage assessment should be reviewed on an ongoing basis as part of the two-yearly Status Reports, with a view to incorporating developments in the updated design for the CCP. RWE Generation UK will keep under review the various pre- and post-combustion options.

4.4 CO_2 Transport

4.4.1 Overall Route

There are various options available for transporting CO_2 from point of capture to final geological storage, including onshore and offshore transportation by pipeline, potentially use of rail or road tankers and offshore transportation by pipeline or shipping. It is considered that onshore transportation by road or rail is not likely to be economically feasible due to the volume of CO_2 required to be transported and the expectation that offshore storage is likely to be required.

It is proposed for the purposes of this CCR report that the CO_2 captured from the Proposed Development will be transported to the storage site via pipeline. It is considered that shipping may have a role for the Proposed

[13] Energy Infrastructure Development Applications: Carbon Capture Readiness Decisions, UK Government. Available online: https://www.gov.uk/government/collections/energy-infrastructure-development-applications-carbon-capture-readiness-decisions

Development given the predicted CO_2 annual tonnages requiring transportation to storage, given the flexible and intermittent nature of operation of the plant and in the event that policy and market forces do not encourage suitable combined or centralised pipeline infrastructure to collect emissions from multiple sites or sources in this location. This may have a beneficial effect on the economic viability of any carbon capture scheme. This has not been assessed further in this report as the use of a dedicated pipeline represents the conservative economic assumption for the transport requirements not exceeding 1,000km[14].

The most likely option identified at present would be a pipeline leaving the site heading east directly offshore before heading northwest along the coastline towards the gas terminal at Bacton. The surrounding areas of the power plant is highly constrained with the industrial and residential buildings. Therefore, no onshore option appears to be possible to allow for the construction of a high-pressure CO_2 pipeline.

From Bacton gas terminal, a second offshore pipeline will head northwards to the Barque Gas Field storage site in the SNS Basin using a similar corridor as existing pipelines leaving Bacton gas terminal. This is the preferred potential route which is considered in this CCR study. Land easements and permissions would also need to be obtained but any new CCS project would need separate consenting at that time, so those land agreements would be secured as part of the consenting process.

As required by the CCR Guidance, the indicative route of the CO_2 pipeline has been developed which shows:

- a 1km wide corridor for the first 10km of transport pipework from the site of the Proposed Development; and
- a 10km wide corridor thereafter to the chosen point(s) for the pipeline going offshore.

The initial section of the CO_2 pipeline from the CCP to Bacton gas terminal is shown in Appendix B and is approximately 48km in length. The final offshore section of the CO_2 pipeline from Bacton gas terminal to Barque gas field is shown in Appendix C and is approximately 80km in length.

4.4.2 Predominantly Onshore Transport prior to transition

Due to the Proposed Development's distance from the UK's eastern coastline, the pipeline is likely to need a very short onshore pipe before using an offshore pipe heading towards Bacton Gas Terminal.

Developing networks where clusters of power stations or other heavy industry adopting CCS could use the same pipeline infrastructure would be much more practical and economic and minimise environmental impacts compared to each installation building its own separate pipeline.

4.4.3 Predominantly Offshore Transport

A sub-sea pipeline would typically be laid using specialist trenching and laying barges at low tide or low current periods to minimise disruption. Where the level of disruption to the environmentally sensitive areas (which is typically caused by trenching) is deemed to be unacceptable, other techniques such as thrust boring or directionally drilled boreholes may be feasible. Both boring methods avoid the need to disturb existing habitats. If these alternative boring techniques are not feasible it may be possible to plan activities around breeding and migration seasons or consider species and habitat relocation. This would be established and considered at all stages of the outline design, EIA and subsequent detailed design of the CCS development in the future.

Navigation of wind farm sites and associated cabling, dredging areas, existing pipeline infrastructures and disposal sites via the proposed route would be feasible. Experience gained by the natural gas and oil industry in laying pipelines in the SNS Basin would provide the techniques and expertise required to accomplish this.

The routes of shipping lanes are not anticipated to be a significant barrier to this form of transport, because the pipeline would run along the seabed at a depth sufficient enough to allow ships free passage. The impacts of the offshore CO_2 pipeline would be minimised by keeping the route of the pipeline a sufficient distance away from the shore so as not to impact any designated coastline. It is therefore considered that a feasible route exists to remove the captured CO_2 from the Proposed Development to either of the storage sites identified.

4.5 Conclusion

A detailed technical assessment for the CCP has been completed within this study, addressing each advisory checklist items found within Annex C of the CCR Guidance.

[14] Chapter 4 – Transport of CO_2, IPCC, 2018. Available online: https://www.ipcc.ch/site/assets/uploads/2018/03/srccs_chapter4-1.pdf

Based on the CCP equipment footprint and indicative CCP layout produced within Appendix A, there appears to be insufficient available area within the site boundary for construction of the CCP. At least 7,000m^2 of permanent additional land outside the current site boundary will need to be acquired to replace storage, maintenance and laydown areas for the existing power plant displaced by the CCP. At least 20,475 m^2 of temporary additional land outside the current site boundary will be required for construction of the CCP.

An assessment of the technical feasibility of CO_2 storage and transport has been completed within this study with a potential storage site with sufficient capacity, Barque gas field, and a CO_2 pipeline route from the Proposed Development identified.

5. Economic Assessment

5.1 Retrofit

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 CCS economically viable. The carbon market remains very volatile; however, 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 (450 g/kWh at baseload) that does not require the use of CCS on efficient gas-fired power stations, this may change in the future as part of the Net Zero commitment. These issues are however beyond the control or scope of the Proposed Development.

At the time of writing, only a general guidance on the methodology to follow to demonstrate economic feasibility of a CCS scheme is available from the DECC. Therefore, in order to develop this economic assessment, several assumptions such as anticipated infrastructure requirements, utilities (electricity, gas and steam) usage, future carbon prices etc. regarding the proposed CCS scheme have been made.

In the absence of a defined methodology available from regulators, it is understood to be up to developers to develop a suitable methodology for assessing the economic viability of a proposed CCS schemes as part of the CCR assessments. 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 capital expenditure, fuel price, carbon price, capture costs, and CO_2 transport and storage costs. From the 2018 Wood report assessing carbon capture technologies, costs are expected to diminish as implementation moves from demonstration of First of a Kind to Nth of a Kind (NOAK) roll out of installed capacity[15]. Based on a recent AECOM cost estimation conducted as part of a pre-FEED study for a CCGT-CCP, CAPEX and OPEX estimates for the CCP at the Proposed Development have been approximated, and the difference in levelised cost of generation (£/MWh) for CCS abated and unabated CCGT have been compared to determine whether CCS retrofit is potentially viable.

The cost of retrofit of CCS is anticipated to attract a higher CAPEX than for CCS fitted as part of a new-build, in particular for sites that may be space constrained.

Costs associated with pipeline transport and geological storage of CO_2 are uncertain, and highly dependent on the potential for network facilities. 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.

5.1.1 Methodology

An assessment of the costs has been made using a Discounted Cash Flow (DCF) analysis technique, based on the DECC Levelised Cost of Electricity (LCOE) analysis (UK Electricity Generation Costs Update, 2010).

A DCF has been prepared using estimated CAPEX and OPEX costs associated with the project. The LCOE is the lifetime cost including CAPEX and OPEX, discounted to determine the present value against future value (money available today assumed to be worth less in the future) and converted into the equivalent unit cost of generation as £/MWh. A discount rate of 8.9% has been considered within this study to reflect the level of risk and complexity of abated CCGT plants compared to an unabated CCGT plant (Wood, 2018).

The analysis has been used to estimate the difference in LCOE costs for the two modes of operation for the project: the unabated mode (CCGT plant only) compared to the abated mode with the CCP retrofitted to the CCGT plant. The LCOE calculation has been undertaken assuming the unabated mode represents 'base case' for the project. Costs associated to both abated and unabated modes of the CCGT plant, for example fuel costs, have not been considered as it is assumed that this will be the same for both modes.

The following parameters have been considered in calculating the differences in LCOE between the two modes:

- CAPEX of the CCP retrofit

[15] Benchmarking State-of-the-art and Next Generation Technologies, Wood, 2018. Available online: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/864688/BEIS_Final_Benchmarks_Report_Rev_4A.pdf

- Fixed OPEX relating to the operation of the CCP, includes labour, maintenance, administration & overheads
- Variable OPEX relating to the operation of the CCP, includes waste, chemicals & consumptions
- CO_2 transport & storage costs
- Parasitic cost of CCS, includes the energy penalty on the steam turbine associated with CCP operating and the electrical consumption of the CCP equipment
- Lost generation revenue from power plant downtime during final year of CCP construction (export generation minus fuel costs for that year)
- CO_2 emissions cost based on the difference between unabated and abated

The parameters listed above represent additional costs associated with retrofitting a CCP to a CCGT plant, apart from the cost associated with the level of CO_2 emissions which will appear as a cost saving. This parameter will be dependent on the carbon price used within the assessment.

5.1.2 Assumptions

The abated model includes estimated CAPEX associated with CCP retrofit, based on scaled costs from Pre-FEED studies, and OPEX including indicative costs associated with transport and storage of CO_2, utilities (parasitic electricity and steam) and chemical consumption, and waste emissions associated with the CCP operation. Costs for labour, maintenance, administration and overheads associated with CCS operation are estimated in the OPEX.

Costs of transport and storage of CO_2 are based on data published by Element Energy for BEIS in 2018[16] and adjusted to the assessment cost basis. Table 5-1 summarises the key assumptions used within the economic assessment.

Table 5-1 Economic Assessment Assumptions

Parameter	Value
Assessment Cost Basis	£-2022
Maximum Plant Output (Unabated)	430 MWe gross
Net Efficiency	56%
Plant Lifetime (assuming 2027 as first year of operation)	24 years (circa)
Construction Duration	3 years
CO_2 Capture Rate	95%
Discount Rate	8.9%
Total CO_2 Emissions (Unbated)	148 tCO_2/hr
Total CO_2 Emissions (Abated)	7 $atCO_2$/hr
Total Energy Penalty for Abated CCP	59 MWe
CAPEX of CCP Retrofit	£245,500,000
Fixed OPEX of CCP per annum	£10,000,000
Average Variable OPEX of CCP per annum	£6,900,000
CO_2 Transport and Storage Price	£22 / tCO_2

An anticipated forecast of operating hours for the retrofit CCP site up to 2050 has been provided by RWE, including the initial unabated operation during the years prior to full CCP operation. Within this assessment, the unabated plant is assumed to have the same operating regime as the abated plant as well as discount rate.

Forecast prices for both carbon and electricity used within this assessment are based on BEIS' Green Book supplement guidance data (2020)[17] and Updated Energy & Emission Projections 2019 report respectively. The

[16] Shipping CO_2 – UK Cost Estimation Study, Element Energy, 2018. Available online: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/761762/BEIS_Shipping_CO2.pdf

[17] Green Book supplementary guidance: valuation of energy use and greenhouse gas emissions for appraisal BEIS, 2021. Available online: https://www.gov.uk/government/publications/valuation-of-energy-use-and-greenhouse-gas-emissions-for-appraisal

values used for operating hours, carbon and electricity prices from 2022 to 2050 are summarised within Appendix D**Error! Reference source not found.** These prices have been adjusted to £-2022 cost basis using the UK GBP deflator index presented within the Green Book supplementary guidance.

For the purpose of this assessment, the Green Book central carbon values have been used to illustrate the potential cost of residual emissions. This is not meant to presume a future UKETS price or arrangement. Its sole purpose is to demonstrate what trade-off UK-based sites might have to make when transitioning their sites to a net zero business environment.

5.1.3 Result

The results of the economic assessment are presented in Table 5-2 and graphically in Figure 5-1. From this assessment, it appears that the cost savings from reducing the CO_2 emissions from the site by 95% will be greater than the additional costs associated with retrofitting the CCP based on the assumptions and input values used.

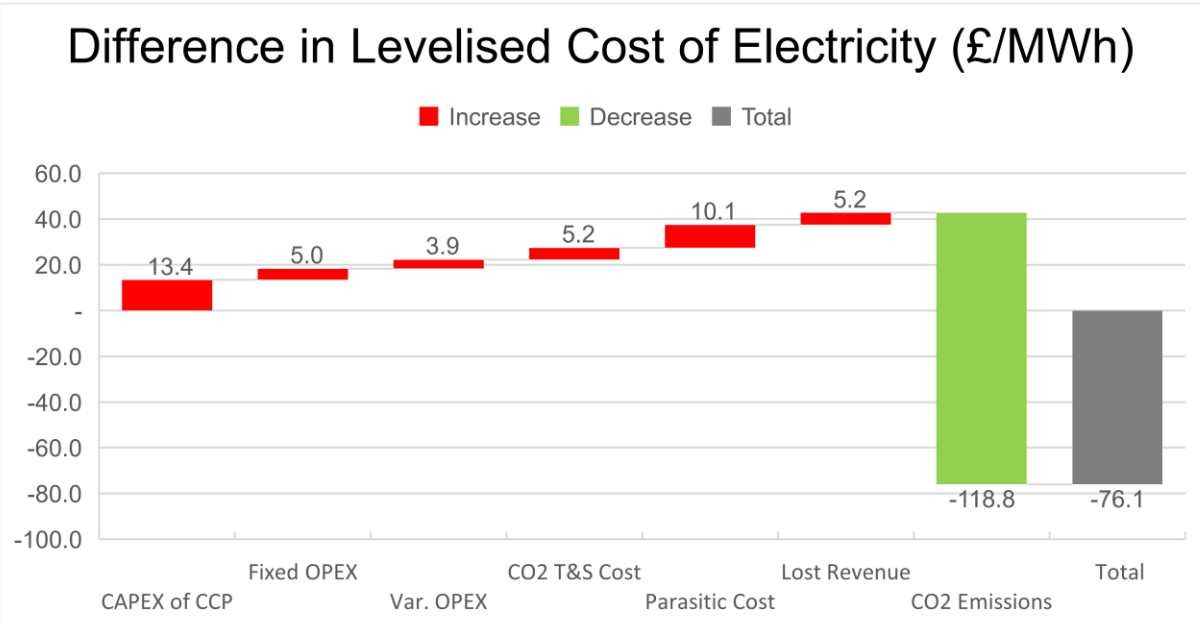
The carbon floor price within the UK Emissions Trading Scheme (UK ETS) is currently set at £62/tCO_2 for the 2022/2023 scheme year; however BEIS modelling assumes a central price of carbon up to £248/tCO_2 in 2022 increasing to £377/tCO_2 by 2050.

Within the scope of this CCR study, it is noted that the publicly available data has been developed on the basis of CCGT plant operating at baseload in order to determine full chain lifetime costs amortised over the total lifetime tonnage of CO_2 captured, transported and stored.

Table 5-2 Difference in Levelised Cost of Electricity Generation against unabated plant

Parameter	Difference in LCOE (£/MWh)
CAPEX of CCP	13.4
Fixed OPEX	5.0
Var. OPEX	3.9
CO_2 T&S Cost	5.2
Parasitic Cost	10.1
Lost Revenue	5.2
CO_2 Emissions	-118.8
Total	-76.1

Figure 5-1 Waterfall chart to show the difference in Levelised Cost of Electricity Generation



A sensitivity analysis of the economic assessment was performed with different carbon price values to explore the impact on CO_2 emission costs for the CCP retrofit. Using the low prices of carbon reported within BEIS' Green Book supplementary guidance, the cost savings from capturing the CO_2 throughout the lifetime of the CCP is approximately £59.4/MWh compared to £118.8/MWh using the central prices. Therefore, this still suggests that the CCP retrofit is economically viable using the low prices of carbon as the estimated net LCOE difference of the abated plant is £16.7/MWh.

Future deployment of CCS technology in the region, with associated CO_2 pipeline network and lower CAPEX from NOAK technology deployment at the Proposed Development would provide a greater surety of economic viability of CCS.

In summary, whilst deployment of CCS will add significant cost to the operation of any power station, subject to market conditions (based on high level assumptions) it is possible for the Proposed Development to achieve an economically viable carbon capture solution if required in the future.

5.2 Conclusion

The assessment suggests that there are no known economic barriers to capture, transport and storage of emissions of CO_2 from the Proposed Development depending on the carbon price considered. This is subject to an appropriate industrial strategy, the future costs of carbon and the suitability for retrofit of CCS technology to the existing plant.

6. Health and Safety

6.1 Pipeline

Current UK experience of designing and operating CO_2 pipelines is limited and only some pipeline design codes include it as a relevant fluid within their scope. European Standards implemented in the UK as British Normative Standards (BS EN series) and supported by published documents (such as the British Standards PD series) provide a sound basis for the design of pipelines.

The DECC CCR Guidance 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 '*Comparison of risks from carbon dioxide and natural gas pipelines*' (Health and Safety Executive, 2009) concluded that a loss of containment event from a dense or supercritical phase CO_2 pipeline presents a similar level of risk to a release from a high-pressure natural gas pipeline. As such, designers of CO_2 pipelines should consider applying a similar fluid hazard categorisation (chosen from an established pipeline design code) to that applied to high pressure natural gas pipelines.

The pipeline would therefore be considered to be a Major Accident Hazard Pipeline (MAHP).

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.

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

It is considered that – based on the evaluation undertaken on behalf of National Grid for the consenting of the Yorkshire - Humber carbon pipeline – the H&S implications and risks of any dense phase carbon pipeline can be appropriately mitigated through the routing and design of the pipeline. 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.

6.2 On-Site

There is the potential for dense phase CO_2 to be present in pipework or vessels onsite once it has been captured and compressed prior to transport. CO_2 is currently classified as 'substance hazardous to health' under the Control of Substances Hazardous to Health Regulations 2002 (COSHH).Accidental release of large quantities of CO_2 (particularly, dense-phase CO_2) could result in a major accident hazard.

No bulk storage of dense or gaseous phase CO_2 is proposed in the initial CCS design for the Proposed Development. The only 'stored' CO_2 on site would therefore be the inventory in the CCP and on-site pipework, and this is envisaged to be considerably less than five tonnes. It is envisaged that the Proposed Development will require consent under the Planning (Hazardous Substances Consent) 2015 Regulations regime and may trigger the need for lower tier COMAH licensing. This will be determined at the FEED stage.

A Health and Safety Plan covering the works, commissioning and operation of the Proposed Development will be prepared by the Applicant. For design and construction, a competent and adequately resourced Construction (Design and Management) (CDM) Coordinator and Principal Contractor will be appointed. The Applicant will monitor that its own staff, its designers and contractors follow the Approved Code of Practice (ACoP) laid down by the CDM Regulations 2015.

Written procedures clearly describing responsibilities, actions and communication channels will be available for operational personnel dealing with emergencies. Procedures will be externally audited, and contingency plans written in preparation for any unexpected complications.

The Proposed Development is using 'safety in design' principles to take into consideration safety issues and risks within the ongoing design, to reduce risks from the installation, as a whole, to as low as reasonably practicable (ALARP). As part of the layout evolution, the following safety in design mitigation hierarchy has been adopted:

- eliminate a hazard; in preference to;
- control the hazard; in preference to;
- provide personal protective equipment (PPE).

Design mitigation at the current concept design stage includes consideration of potential CO_2 releases and includes, (but is not limited to):

- careful equipment and material selection;
- siting of high-pressure carbon dioxide equipment considering areas of potential exposure and prevailing wind direction;
- incorporation of gas leak detection systems; and
- consideration of venting arrangements.

As the design of the Proposed Development progresses, further consideration will continue, potentially including additional dispersion modelling to confirm whether design mitigation is considered ALARP for the installation as a whole (i.e. future site users and general public). Additionally, other hazardous substances present in a Carbon Capture Plant such as Nitrosamines, Heat Stable Salts, Amines, sulphuric acid and sodium hydroxide shall be identified. Further detailed evaluation and quantitative risk assessment will continue throughout the FEED stage when the Proposed Development is further defined.

6.3 Conclusion

An assessment of the health and safety considerations for both the CO_2 pipeline and on-site facilities have been considered within this study.

Based on the CCR Guidance, the CO_2 pipeline is considered to be a MAHP and therefore the necessary safety requirements will be completed as part of the detailed design of the pipeline.

The Proposed Development is likely to require consent under the Planning (Hazardous Substances Consent) 2015 Regulations regime which may trigger the need for lower tier COMAH licensing.

A Health and Safety Plan covering the works, commissioning and operation of the Proposed Development will be prepared by the Applicant at the detailed design stage as well as formal documentation detailing the procedures to follow during emergencies.

The Proposed Development has applied 'safety in design' principles within the ongoing design to manage safety risks. Further evaluation of safety hazards and quantitative risk assessment will continue throughout the FEED stage when the Proposed Development is further defined.

7. Conclusion

The purpose of this document is to evaluate the technical and economic feasibility of incorporating Carbon Capture technology to the Proposed Development. Technical and Economic feasibility have been assessed in accordance with the criteria presented by the Department of Energy and Climate Change (DECC) November 2009 guidance 'Carbon Capture Readiness (CCR) – A Guidance Note for Section 36 Electricity Act 1989 consent applications.'

The technical feasibility assessment of the proposed Carbon Capture and Storage (CCS) technology has established the likely sizing and utility demand. The site layout for the Proposed Development shows that there is insufficient space for the CCS technology and necessary auxiliary equipment within the existing site boundary .

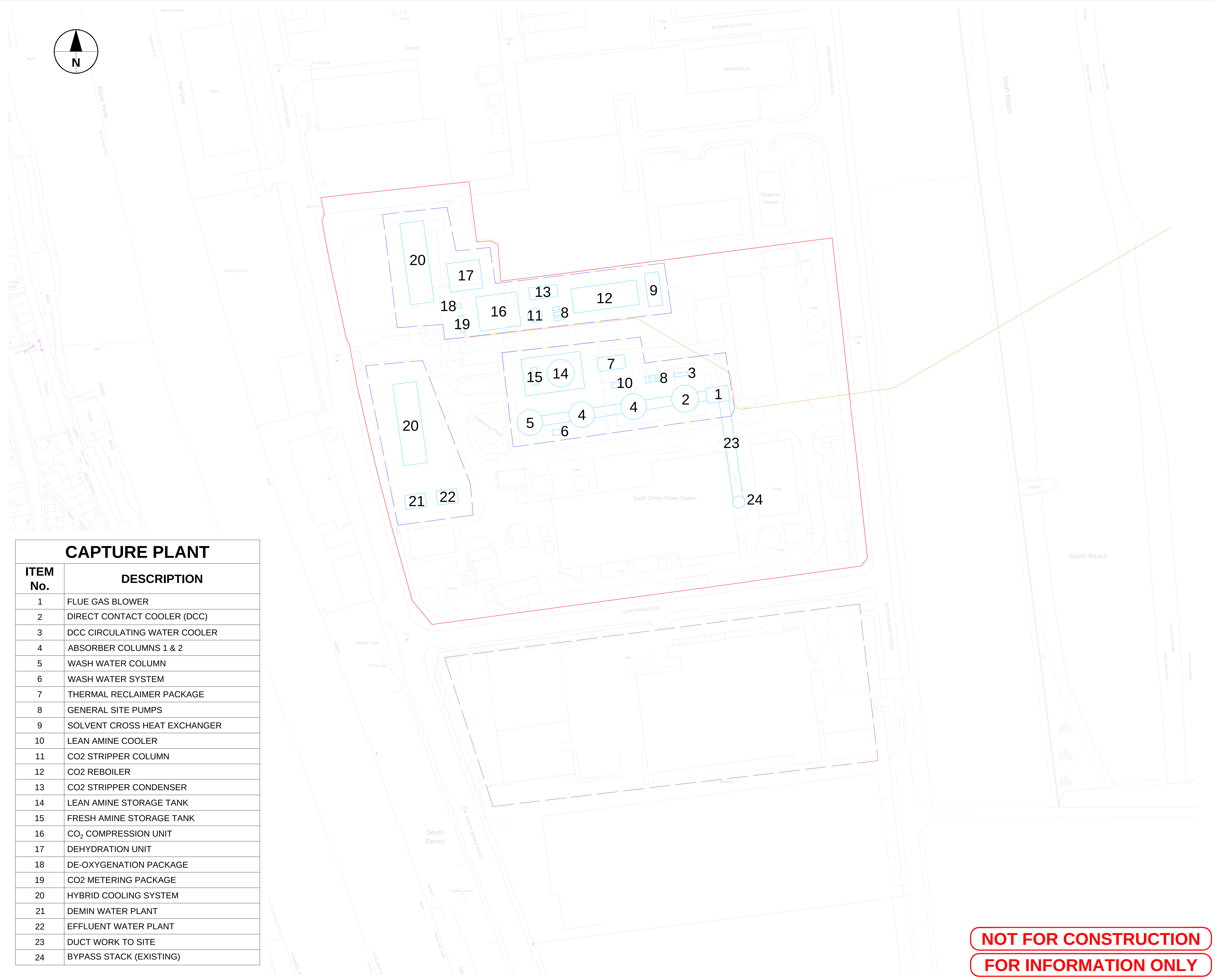
The CO_2 storage locations currently proposed for the Proposed Development is the Barque gas field, with a storage capacity capable of accepting the carbon output from the Proposed Development over its anticipated operational life. It is intended that the CO_2 captured from the Proposed Development will be transported to the storage site via pipeline using a similar corridor route to that of the natural gas infrastructure pipeline.

Based on an economic assessment, the findings suggest that retrofitting a CCP to an existing CCGT plant is economically viable due to significant costs associated with CO_2 emissions using the current DESNZ carbon price predictions. However, these prices illustrate the potential cost of residual emissions and are not meant to presume a future UKETS price or arrangement.

The economic viability of the CCP is contingent on the outcome of the selection process under the Government CCS Infrastructure Fund and negotiations under the Dispatchable Power Agreement, as well as the long-term carbon price.

The assessment therefore suggests that there should be no known economic barriers to capture, transport and storage of emissions of CO_2 from the Proposed Development subject to an appropriate industrial strategy, the future costs of carbon and the technical feasibility of retrofitting CCS technology..

Appendix A CCR Layout



CAPTURE PLANT

ITEM No.	DESCRIPTION
1	FLUE GAS BLOWER
2	DIRECT CONTACT COOLER (DCC)
3	DCC CIRCULATING WATER COOLER
4	ABSORBER COLUMNS 1 & 2
5	WASH WATER COLUMN
6	WASH WATER SYSTEM
7	THERMAL RECLAIMER PACKAGE
8	GENERAL SITE PUMPS
9	SOLVENT CROSS HEAT EXCHANGER
10	LEAN AMINE COOLER
11	CO2 STRIPPER COLUMN
12	CO2 REBOILER
13	CO2 STRIPPER CONDENSER
14	LEAN AMINE STORAGE TANK
15	FRESH AMINE STORAGE TANK
16	CO_2 COMPRESSION UNIT
17	DEHYDRATION UNIT
18	DE-OXYGENATION PACKAGE
19	CO2 METERING PACKAGE
20	HYBRID COOLING SYSTEM
21	DEMIN WATER PLANT
22	EFFLUENT WATER PLANT
23	DUCT WORK TO SITE
24	BYPASS STACK (EXISTING)

Project Management Initials: Designer: ____ Checked: ____ Approved: ____

Last saved by: JAMIE.CALVERT(2022-06-06) Last Plotted: 2022-06-06 AutoCAD Version: 23.1S (LMS TECH)
Filename: C:\USERS\JAMIE.CALVERT\AECOM\RWE CCR - CONFIDENTIAL BID - FOLLOW ON JAN 2022\0400 TECHNICAL\GREAT YARMOUTH\DRAWINGS\GREAT YARMOUTH POWER STATION - INITIAL SITE LAYOUT DRAWING - REV 4.DWG

AECOM

PROJECT

RWE GREAT YARMOUTH CARBON CAPTURE READINESS STUDY

CLIENT

RWE GENERATION UK

CONSULTANT

AECOM
Portwall Place
Bristol BS1 6NA
+44 (0) 117 001 7000 tel 7099 fax
www.AECOM.com

LEGEND

- RWE LAND HOLDING
- AREA AVAILABLE FOR CARBON CAPTURE PLANT
- CARBON CAPTURE EQUIPMENT
- INDICATIVE CO2 PIPELINE
- POTENTIAL LAYDOWN AREA

NOTES

1. DRAWING IS FOR INDICATIVE PURPOSES ONLY
2. APPROXIMATE CARBON CAPTURE PLANT FOOTPRINT IS $16{,}200M^2$ (EXCLUDING DUCT WORK)
3. INDICATIVE AREA AVAILABLE FOR CARBON CAPTURE PLANT IS $20{,}300M^2$
4. APPROXIMATE DUCT WORK LENGTH FROM HRSG TO FLUE GAS BLOWERS IS 60M

0 25 50 m
1:1000

APPROVED FOR ISSUE

I/R	DRAWN BY	CHECKED	APPROVED
A	JC	KMacK	GC

ISSUE/REVISION

I/R	DATE	DESCRIPTION
A	06/06/2022	INITIAL ISSUE

PROJECT NUMBER

60648701

SHEET TITLE

INDICATIVE CONCEPT LAYOUT OF CCS PLANT FOR GREAT YARMOUTH POWER STATION (ON-SITE)

SHEET NUMBER

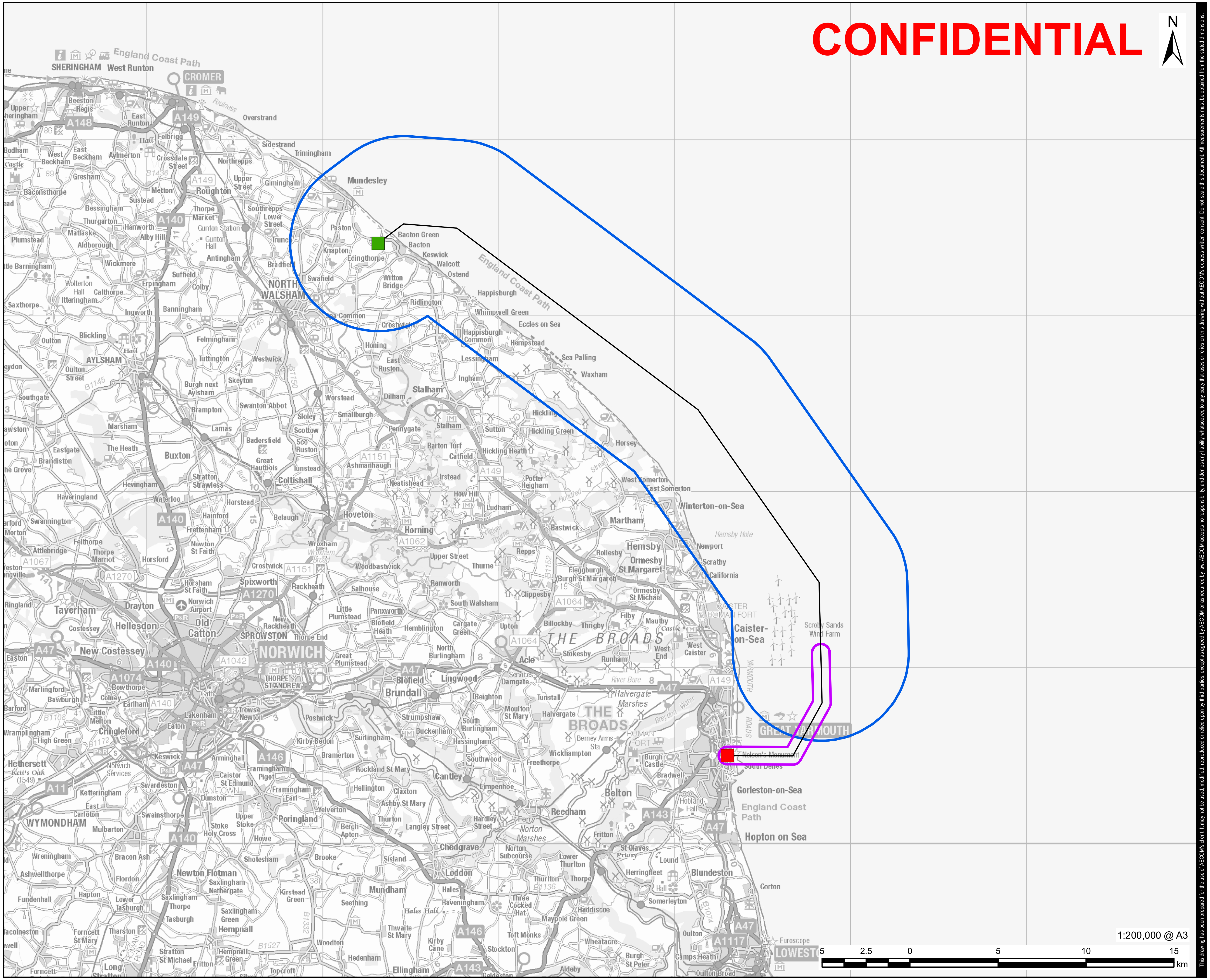
60648701-CCS-03

NOT FOR CONSTRUCTION

FOR INFORMATION ONLY

Appendix B CO_2 Pipeline Route to Gas Terminal

Revision: 1 Drawn: AW Checked: JW Approved: RH Date: 2022-05-24



AECOM

PROJECT

RWE Great Yarmouth Carbon Capture Readiness Study

CLIENT

RWE Generation UK

CONSULTANT

AECOM Limited
Midpoint, Alencon Link
Basingstoke, Hampshire
RG21 7PP
www.aecom.com

LEGEND

- Great Yarmouth Power Station
- Bacton Gas Terminal
- Proposed Offshore Gas Pipeline (Indicatively drawn)
- Proposed Offshore Gas Pipeline - 1km Corridor (First 10km)
- Proposed Offshore Gas Pipeline - 10km Corridor

NOTES

ISSUE PURPOSE

DRAFT

PROJECT NUMBER

60648701

FIGURE TITLE

Potential CO2 Offshore Route from Site to Gas Terminal

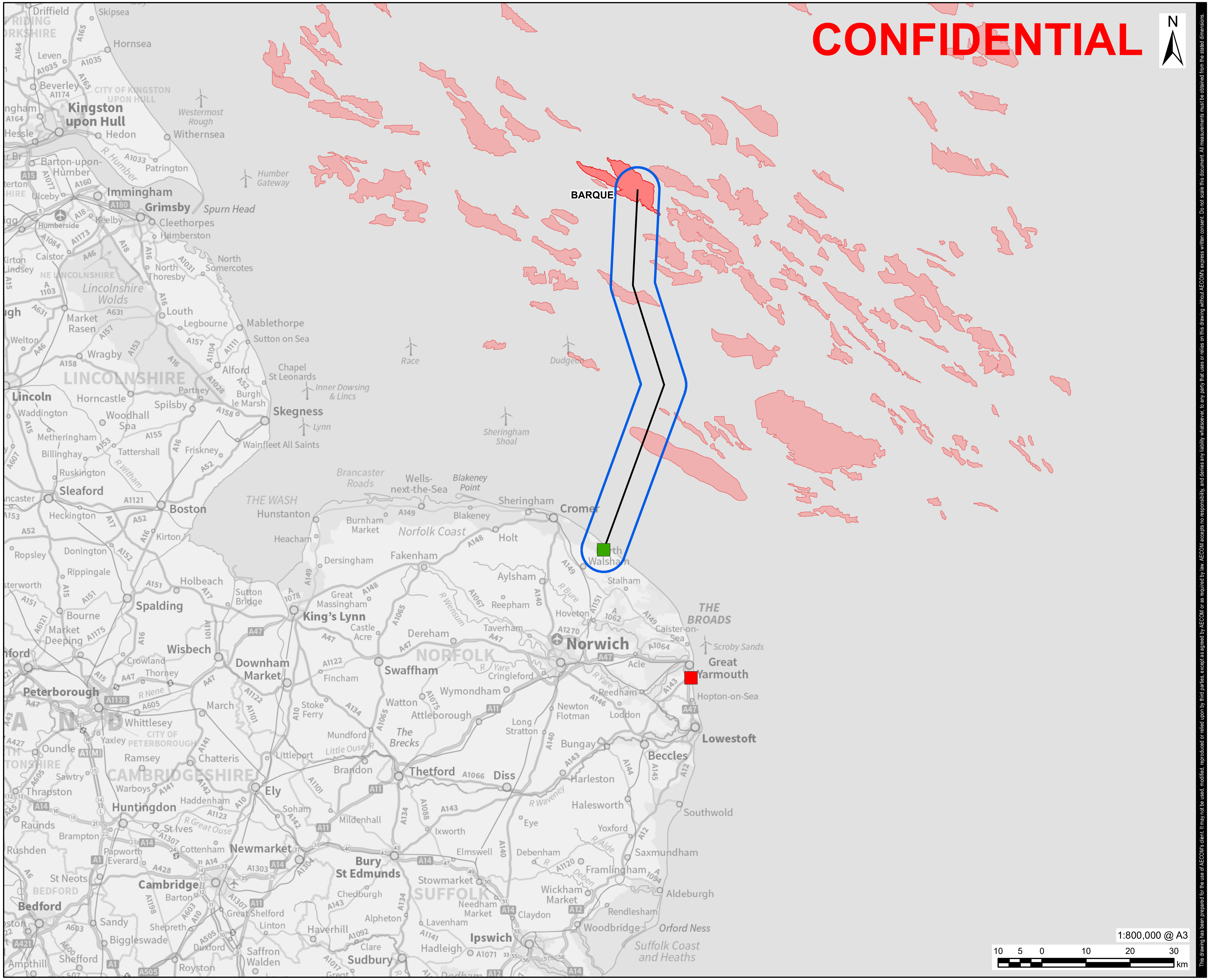
SHEET NUMBER

60648701-CP-301

Filename: Y:\UKNCL2-IE\Environmental Group Management\Carbon Capture Readiness\02_Maps\60648701_CP_301_Great_Yarmouth.mxd

Appendix C CO_2 Pipeline Route to Storage Site

Revision: 1 Drawn: AW Checked: JW Approved: RH Date: 2022-05-24



AECOM

PROJECT

RWE Great Yarmouth Carbon Capture Readiness Study

CLIENT

RWE Generation UK

CONSULTANT

AECOM Limited
Midpoint, Alencon Link
Basingstoke, Hampshire
RG21 7PP
www.aecom.com

LEGEND

- Great Yarmouth Power Station
- Bacton Gas Terminal
- Proposed Offshore CO2 Route
- Proposed Offshore CO2 Route - 10km Corridor
- Offshore Oil and Gas Field

NOTES

Contains Ordnance Survey Data © Crown Copyright and database right [2022].
© National Grid UK.

Contains information provided by the OGA.

ISSUE PURPOSE

DRAFT

PROJECT NUMBER

60648701

FIGURE TITLE

Potential CO2 Offshore Route from Gas Terminal to Storage Site

SHEET NUMBER

60648701-CP-302

Filename: Y:\UKNCL2-IE\Environmental Group Management\GIS Management\Carbon Capture Readiness\02_Maps\60648701_CP_302_Great_Yarmouth.mxd

Appendix D Forecast Operational Hours & Prices for Economics Assessment

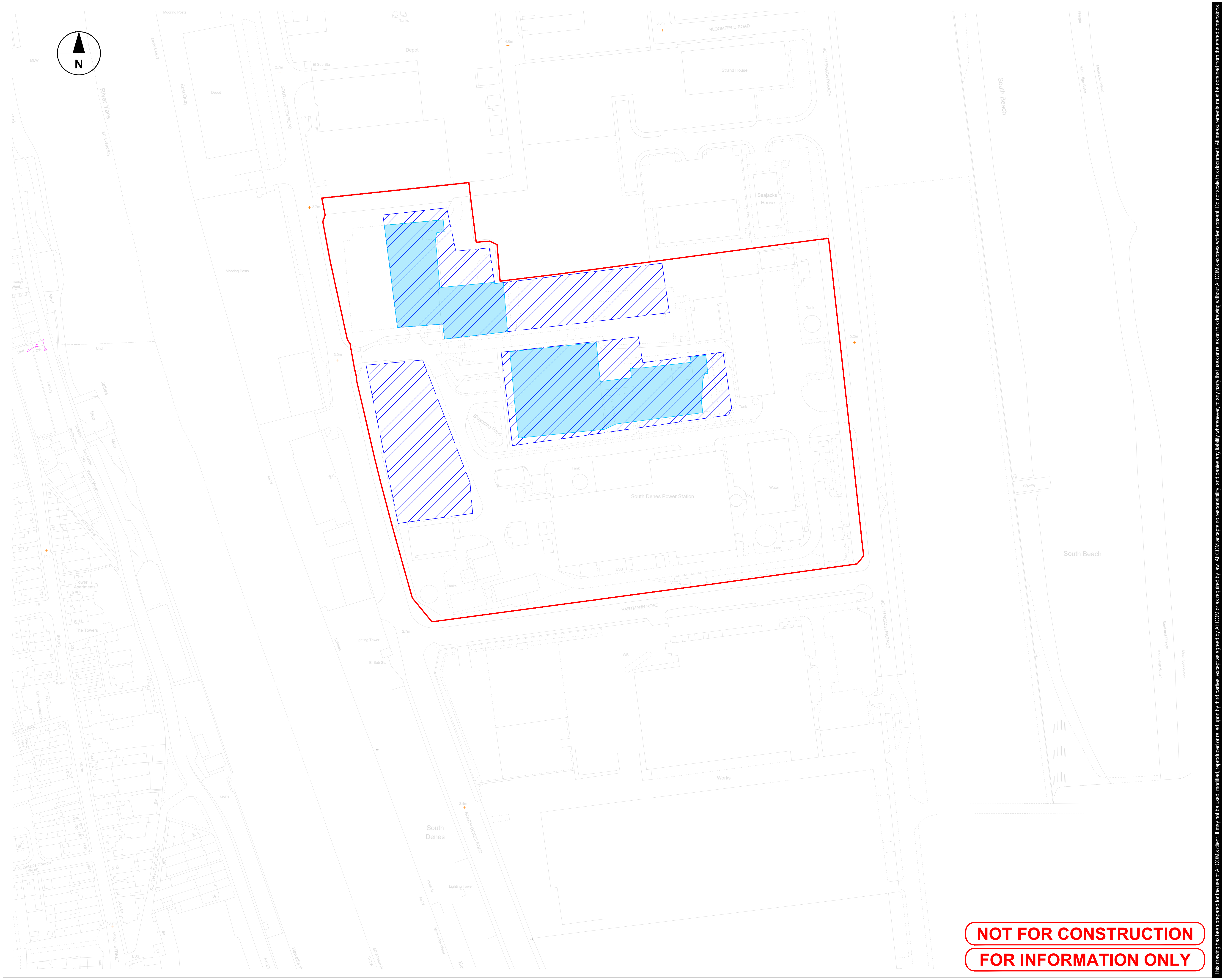
The following table summarises the operating regime forecast for the retrofit CCP site, the various carbon prices used within the sensitivity analysis and the electricity prices. All prices stated below have been adjusted to a cost basis of 2022 using the UK GBP deflator index presented within the Green Book supplementary guidance.

Year	Running Hours	Carbon Price – Central (£/MWh)[1]	Carbon Price – Low (£/MWh)[1]	Electricity Price (£/MWh)[3]
2022	3100	247.6	123.8	0.061
2023	3300	251.4	125.7	0.060
2024	2900	255.2	127.6	0.061
2025	2500	259.1	129.5	0.061
2026	2400	263.0	131.5	0.060
2027	7300	267.0	133.5	0.061
2028	7100	271.1	135.6	0.060
2029	6900	275.2	137.6	0.061
2030	6300	279.4	139.7	0.060
2031	5800	283.7	141.8	0.060
2032	5700	288.0	144.0	0.060
2033	5500	292.4	146.2	0.062
2034	5500	296.8	148.4	0.063
2035	5200	301.4	150.7	0.064
2036	5000	306.0	153.0	0.063
2037	4800	310.6	155.3	0.064
2038	4700	315.3	157.7	0.064
2039	4600	320.1	160.1	0.064
2040	4400	325.0	162.5	0.064
2041	4400	329.9	164.9	0.064
2042	4200	334.8	167.4	0.064
2043	4000	339.9	169.9	0.064
2044	4000	345.0	172.5	0.064
2045	3800	350.1	175.1	0.064
2046	3700	355.4	177.7	0.064
2047	3600	360.7	180.4	0.064
2048	3600	366.1	183.1	0.064
2049	3400	371.6	185.8	0.064
2050	3400	377.2	188.6	0.064

Note: 1. Table 3: Carbon values and sensitivities 2020-2100 for appraisal (Central & Low values), Green Book supplementary guidance, BEIS, 2020. Available online: https://www.gov.uk/government/publications/valuation-of-energy-use-and-greenhouse-gas-emissions-for-appraisal

2. Updated Energy & Emissions Projections, Annex M: Growth assumptions and prices, Updated energy and emissions projections: 2019, BEIS, 2019. Available online: https://www.gov.uk/government/publications/updated-energy-and-emissions-projections-2019

Appendix E Site Area Assessment



NOT FOR CONSTRUCTION

FOR INFORMATION ONLY

AECOM

PROJECT

RWE GREAT YARMOUTH CARBON CAPTURE READINESS STUDY

CLIENT

RWE GENERATION UK

CONSULTANT

AECOM
Portwall Place
Bristol BS1 6NA
+44 (0) 117 001 7000 tel 7099 fax
www.AECOM.com

LEGEND

- RWE LAND HOLDING
- AREA REQUIRED FOR CARBON CAPTURE PLANT
- UNAVAILABLE AREA

NOTES

1. DRAWING IS FOR INDICATIVE PURPOSES ONLY
2. TOTAL AREA WITHIN RWE LAND HOLDING IS 57,100M^2
3. TOTAL AREA REQUIRED FOR CARBON CAPTURE PLANT IS 16,200M^2 (EXCLUDING DUCT WORK)
4. TOTAL UNAVAILABLE AREA IS 7000M^2

0 25 50 m
1:1000

APPROVED FOR ISSUE

I/R	DRAWN BY	CHECKED	APPROVED
2	RWG	SA	GC
1	RWG	SA	GC

ISSUE/REVISION

I/R	DATE	DESCRIPTION
2	04/12/2023	FINAL ISSUE
1	28/11/2023	INITIAL ISSUE

PROJECT NUMBER

60648701

SHEET TITLE

SITE AREA ASSESSMENT OF CCS PLANT FOR GYPS FOR S36 VARIATION ORDER

SHEET NUMBER

60648701-CCS-04

Last saved by: GOUGHR(2023-12-04) Last Plotted: 2023-12-04
Filename: C:\USERS\GOUGHR\AECOM\RWE CCR READINESS - GENERAL\400_TECHNICAL\430_TECHNICAL_WORKING_DOCUMENTS\GREAT YARMOUTH\GREAT YARMOUTH - CCR\CCR REPORT FOR LOW AMBIENT S36\DRAWINGS\GREAT YARMOUTH POWER STATION - S36 VO DRAWING - REV 2.DWG
AutoCAD Version: 24.1S (LMS TECH) Project Management Initials: Designer: Checked: Approved:

aecom.com