Intended for
InterGen

Document Type
Report

Date
14 April 2015

SPALDING ENERGY EXPANSION

REVISED CARBON CAPTURE READINESS FEASIBILITY STUDY

Revision History

Revision	*Date*	*Purpose / Status*	*Document Ref.*	*Comments*
1	16/02/2015	Draft for Client Comment	371455-1	
2	10/03/2015	Revised following Client Comments	371455-1	
3	14/04/2015	Final	371455-1	

Prepared By	Reviewed By	Approved By
Emily Agus	**Stephen Loyd**	**Stephen Loyd**
Senior Development and Environmental Engineer	Principal Consultant	Principal Consultant

Ramboll Energy
Rotterdam House
116 Quayside
Newcastle upon Tyne
NE1 3DY
United Kingdom

CONTENTS

LIST OF ABBREVIATIONS 1

1 INTRODUCTION 3

2 CONTEXT (THE PURPOSE OF A CCR FEASIBILITY STUDY) AND METHODOLOGY 5

3 DEVELOPMENT DESCRIPTION 16

4 PROPOSED CO_2 CAPTURE PLANT TECHNOLOGY 19

5 TECHNICAL ASSESSMENT – CCS SPACE REQUIREMENT 24

6 TECHNICAL ASSESSMENT – RETROFITTING AND INTEGRATION OF THE CO_2 CAPTURE PLANT TECHNOLOGY 26

7 TECHNICAL ASSESSMENT – CO_2 STORAGE AREAS 33

8 TECHNICAL ASSESSMENT – CO_2 TRANSPORT 35

9 ECONOMIC ASSESSMENT 39

10 REQUIREMENT FOR HAZARDOUS SUBSTANCES CONSENT 54

11 CONCLUSIONS 57

FIGURES

APPENDICES

LIST OF ABBREVIATIONS

ACC	Air Cooled Condenser
bar a	bar absolute
BAT	Best Available Techniques
CCGT	Combined Cycle Gas Turbine
CCR	Carbon Capture Readiness
CCS	Carbon Capture and Storage
CHP	Combined Heat And Power
CO_2	carbon dioxide
DCS	Distributed Control System
DECC	Department of Energy and Climate Change
DTI	Department of Trade and Industry
ES	Environmental Statement
ES FID	Environmental Statement Further Information Document
ETS	Emissions Trading Scheme
EU	European Union
GJ	Gigajoule
ha	Hectare
HDD	Horizontal Directional Drilling
hp	High Pressure
HRSG	Heat Recovery Steam Generator
HSC	Hazardous Substances Consent
HSE	Health and Safety Executive
IEA	International Energy Agency
IEAGHG	International Energy Agency Greenhouse Gas
IED	Industrial Emissions Directive
IP	Intermediate Pressure
kg	Kilogram
LCPD	Large Combustion Plant Directive
LHV	Lower Heating Value
LP	Low Pressure
MEA	Monoethanolamine
Mt	Megatonne
MW	Megawatt
MWh	Megawatt Hour
Nm^3	Volume (m^3) at 0°C and 1.01325 bar a
NPS	National Policy Statement
NSIP	Nationally Significant Infrastructure Project
OCGT	Open Cycle Gas Turbine
SAC	Special Area of Conservation
SCR	Selective Catalytic Reduction
SEE	Spalding Energy Expansion

SEEL	Spalding Energy Expansion Limited
SNS	South North Sea
SPA	Special Protection Area
SSSI	Site of Special Scientific Interest
t	tonnes
t/h	tonnes per hour

1 INTRODUCTION

1.1 Intention to Vary Consent under Section 36C of the Electricity Act 1989

1.1.1 In March 2009, Spalding Energy Expansion Limited (SEEL) submitted an application for Consent under Section 36 of the Electricity Act 1989 (the Original Consent Application) to the Secretary of State for Energy and Climate Change (the Secretary of State) via the Department of Energy and Climate Change (DECC) to construct a 900 megawatt (MW) Combined Cycle Gas Turbine (CCGT) generating station to be known as Spalding Energy Expansion (SEE). In addition, a direction that planning permission be deemed to be granted under Section 90 of the Town and Country Planning Act 1990 was also sought.

1.1.2 Amongst other documents / studies, the Original Consent Application was accompanied by an Environmental Statement (ES) (the March 2009 ES) and a Carbon Capture Readiness (CCR) Feasibility Study (the Original CCR Feasibility Study).

1.1.3 Following submission of the Original Consent Application, the Environment Agency released both draft (April 2009) and final (November 2009) versions of the CCR Guidance. Furthermore, the Environmental Agency (in an e-mail dated 17 September 2009) raised a number of questions relating to the Original CCR Feasibility Study. To bring the Original CCR Feasibility Study in line with the CCR Guidance and to respond to the Environment Agency's questions, in January 2010 a Consolidated CCR Feasibility Study was prepared.

1.1.4 On 11 November 2010, Consent under Section 36 of the Electricity Act 1989 and deemed planning permission under Section 90 of the Town and Country Planning Act 1990 was granted (the Original Consent) for SEE.

1.1.5 Based on a number of influencing factors since the Original Consent was granted, SEEL is submitting an application under Section 36C of the Electricity Act 1989 to the Secretary of State via DECC for the Original Consent to be varied (the Variation Application).

1.1.6 If the Original Consent is varied as per the Variation Application, SEE will provide up to 945 MW of power generation capacity. In providing up to 945 MW of power generation capacity, the Proposed Development will either comprise:

- Scenario 1: Up to 945 MW of CCGT units; or,
- Scenario 2: Up to 645 MW of CCGT units and less than 300 MW of Open Cycle Gas Turbine (OCGT) units.

1.1.7 In addition, if the Original Consent is varied as per the Variation Application, the commencement of the deadline for the Consent will be 5 years from the date of granting the variation. Similarly, the commencement deadline for the deemed planning permission will be 5 years from the date of granting the variation.

1.2 The Purpose of this Document

1.2.1 To accompany the Variation Application, SEEL is providing the following information to DECC:

- An Environmental Statement Further Information Document (ES FID) (the Variation Application ES FID), which includes (amongst other items):
  - The rationale for proposing that the Original Consent is varied;
  - An assessment of whether the likely significant effects on the environment of the Proposed Development differ from those described in the March 2009 ES; and,
    - Where there is potential for the likely significant effects to differ, an updated impact assessment;
    - Where there is no potential for the likely significant effects to differ, an explanation and / or supporting information.

- A Revised Combined Heat and Power (CHP) Assessment;
- A Revised CCR Feasibility Study; and,
- A Supplementary Flood Risk Assessment.

1.2.2 This Document is the Revised CCR Feasibility Study which accompanies the Variation Application.

2 CONTEXT (THE PURPOSE OF A CCR FEASIBILITY STUDY) AND METHODOLOGY

2.1 Context

EU Directive on the Geological Storage of Carbon Dioxide

2.1.1 On 17 December 2008, the European Union (EU) agreed the text of a new directive on the geological storage of carbon dioxide. On 5 June 2009, this text was published as the Directive on the geological storage of carbon dioxide (Directive 2009/31/EC) (the Carbon Capture and Storage (CCS) Directive) in the Official Journal of the European Union and came into force on 25 June 2009.

2.1.2 The CCS Directive required an amendment to Directive 2001/80/EC (commonly known as the Large Combustion Plant Directive (LCPD)) such that Member States are to ensure that operators of all combustion plants with an electrical capacity of 300 megawatts (MW) or more (and for which the construction / operating licence was granted after date of the CCS Directive) have assessed whether the following conditions are met:

- Suitable storage sites for carbon dioxide (CO_2) are available;
- Transport facilities to transport captured CO_2 to the storage sites are technically and economically feasible; and,
- It is technically and economically feasible to retrofit for the capture of CO_2.

2.1.3 The assessment of whether these conditions are met is to be submitted to the relevant competent authority who use the assessment (and other available information) in their decision-making process. If the conditions are met, the competent authority is to ensure that suitable space is set aside for the equipment necessary to capture and compress CO_2.

2.1.4 In the UK the relevant competent authority in respect of energy matters is DECC, which must ensure that the requirements of the relevant EU Directives are implemented.

2.1.5 It should also be noted that the requirement for the assessment is included in the more recent Directive 2010/75/EU on industrial emissions (integrated pollution prevention and control) (the Industrial Emissions Directive (IED)).

UK Government Policy

2.1.6 In June 2008, the UK Government published "*Towards Carbon Capture and Storage: A Consultation Document*" to seek views on the steps it could take to prepare for and support both the development and deployment of CO_2 capture technologies. A response to this consultation was published in April 2009, alongside information on the UK Government's CCR Policy and draft CCR Guidance for applicants seeking consent for new combustion power plant with an electrical capacity at or over 300 MW[1].

2.1.7 The CCR Policy applied to new combustion plants with an electrical capacity of 300 MW or more, with effect from 23 April 2009. Under the CCR Policy, all combustion plants with an electrical capacity of 300 MW or more must be CCR and must set space aside to accommodate future CO_2 capture equipment.

2.1.8 The draft CCR Guidance was subject to an eight week consultation period which ended on 22 June 2009. The responses from the consultation period were considered and incorporated, and the final CCR Guidance was published in November 2009[2].

---

[1] Guidance on Carbon Capture Readiness and Applications under Section 36 of the Electricity Act 1989 (DECC, April 2009).
[2] Carbon Capture Readiness (CCR): A Guidance Note for Section 36 Electricity Act 1989 Consent Applications (DECC, November 2009).

UK Government CCR Policy Requirements

2.1.9 The final CCR Guidance states (at paragraph 7) that applicants will be 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 off shore 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; and,*
- *The likelihood that it will be technically and economically feasible within the power station's lifetime, to link it to the full CCS chain, covering retrofitting of carbon capture equipment, transport and storage".*

Further to the above: *"if Applicant's proposals for operational CCS involves 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".*

The Carbon Capture Readiness (Electricity Generating Stations) Regulations 2013

2.1.10 The Carbon Capture Readiness (Electricity Generating Stations) Regulations 2013 (the CCR Regulations) came into force on 25 November 2013, extending across Great Britain. These 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*".

2.1.11 CCR Regulation 2(2) provides 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 –*

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

2.1.12 In terms of a Variation Application, CCR Regulation 6(1) states: *"The appropriate authority must not:*

(a) Vary a Section 36 Consent in respect of a combustion plant with a rated electrical output of less than 300 megawatts in such a way as to enable the plant to have a rated electrical output of 300 megawatts or more; or,

(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 appropriate authority 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")."

2.1.13 Furthermore, CCR Regulation 6(3) states: *"If the appropriate authority:*

(a) Determines that the CCR Conditions are met in relation to a combustion plant; and,

(b) Decides to:

(i) Vary a Section 36 Consent in respect of that plant in the way described in paragraph (1)(a); or

(ii) Vary a relevant Section 36 Consent in respect of that plant in the way described in paragraph (1)(b),

It must ensure that the Section 36 Consent (as varied) includes 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".

2.1.14 It should be noted that the reference to "*all of its expected emissions of CO_2*" (in Regulation 2(2)) and "*all of the CO_2*" (in Regulation 6(3)) indicates that the applicant should be considering all of the CO_2 emissions from their combustion plant, rather than just a certain percentage of it (i.e. 50 per cent or 20 per cent). This is likely derived from the spirit of the CCS Directive (which the CCR Regulations transpose), which does not cover a fraction of the CO_2, but in principle relates to all of the CO_2.

2.1.15 Therefore, for practical purposes, "*all of its expected emissions of CO_2*" and "*all of the CO_2*" can be considered to indicate that the applicant should be considering 'all of the CO_2 emissions from their power plant which can be captured using Best Available Techniques (BAT)'. This is in line with the CCR Guidance which states (at paragraph 11) that: "*Applicants should explain what percentage of these CO_2 emissions they consider will be captured by their proposed capture technology, in keeping with the principle of best practice*".

Requirement for Consideration of CCR in Applications for Consent under Section 36 / 36C of the Electricity Act 1989

2.1.16 As noted in Section 2 (Rationale for Development) of the Variation Application ES FID, current national policy for energy infrastructure (including the construction / extension of a generating station with a generating capacity of more than 50 MW) is provided in the Overarching National Policy Statement (NPS) for Energy (EN-1) (NPS EN-1), and the technology-specific NPSs. Used together, and in accordance with the provisions of Section 104 of the Planning Act 2008, the NPSs form the primary policy basis for decisions made by the Secretary of State on applications for energy infrastructure comprising Nationally Significant Infrastructure Projects (NSIPs) under the Planning Act 2008. However, it is considered that the NPSs also form a material consideration when determining the Variation Application for the Proposed Development.

2.1.17 In terms of consideration of CCR in applications for Consent, NPS EN-1 states (at paragraph 4.7.10) that:

"*To ensure that no foreseeable barriers exist to retrofitting carbon capture and storage (CCS) equipment on combustion generating stations, all applications for new combustion plant which are of a generating capacity at or over 300 MW and of a type covered by the* [LCPD] *should demonstrate that the plant is 'Carbon Capture Ready' (CCR) before consent may be given. The* [Secretary of State] *must not grant consent unless this is the case. In order to assure the* [Secretary of State] *that a proposed development is CCR, applicants will need to demonstrate that their proposal complies with* [the guidance issued by DECC in November 2009] *or any successor to it".*

2.1.18 The guidance issued by DECC in November 2009 is 'Carbon Capture Readiness (CCR): A Guidance Note for Section 36 Electricity Act 1989 Consent Applications'.

2.2 Assessment Methodology

2.2.1 The assessment methodology for this Revised CCR Feasibility Study is shown in Insert 2.1.

INSERT 2.1: ASSESSMENT METHODOLOGY

Step 1
- Establish a high level design concept for the Proposed Development, and determine whether the relevant parts of the Proposed Development are required to be CCR.

Step 2
- Establish the likely CO_2 capture / storage requirement for the parts of the Proposed Development required to be CCR.

Step 3
- Identify the preferred CO_2 capture plant technology for retrofit / integration for the parts of the Proposed Development required to be CCR, and estimate the likely impact of this preferred CO_2 capture plant technology on performance.

Step 4*
- Establish the size of the preferred CO_2 capture plant technology using modelling and information from: CO_2 capture plant technology providers; GTPro, GTMaster and Thermoflex software modelling of CO_2 capture plant technology on generic generating units; and, Microsoft Excel modelling of CO_2 capture plant technology on generic generating units.

Step 5
- Prepare an outline plot level plan to confirm that the preferred CO_2 capture plant technology for the parts of the Proposed Development required to be CCR would fit within the CCS space available.

Step 6
- Using the estimated CO_2 storage requirement, identify an available CO_2 storage area.

Step 7
- Identify pipeline route corridors to transport CO_2 from the propsed SEE site to the identified CO_2 storage area.

Step 8
- Estimate the price of EU Allowances for CO_2 which would be necessary to make the parts of the Propsoed Development required to be CCR feasible with CO_2 capture.

* Please see note below.

2.2.3 In terms of Step 4, in the absence of technology / specific data, professional judgement was used to make the various assumptions required. The sizing of the internal dimensions of the main CO_2 capture plant technology has been based on the FluorDaniel Study 1999[3]. Using these sizings, likely worst case estimates of the external dimensions of the main CO_2 capture plant technology has been based on the Fluor-Statoil Study 2005[4]. The balance of plant items are also based on the Fluor-Statoil Study 2005. The sizing of cooling plant / equipment is based on information from the software modelling.

2.3 Checklist

2.3.1 Based on Insert 2.1 (and the CCR Guidance), a link to where the requirements of the CCR Guidance are met is provided in Table 2.1.

[3] 'Recovery of CO_2 from Flue Gases: Commercial Trends' (FluorDaniel, October 1999).
[4] 'Study and Estimate for CO_2 Capture Facilities for the proposed 800 MW Combined Cycle Power Plant – Tjeldbergodden, Norway' (Fluor-Statoil, April 2005).

TABLE 2.1: CCR FEASIBILITY STUDY CHECKLIST

Requirement	*Description*	*Reference*
Technical Assessment – Space		
Key Requirements of Paragraphs 18 to 19 of the CCR Guidance	An outline plot level plan should be provided which is sufficiently detailed to show: • The footprint of the Proposed Development; • The location of the CO_2 capture plant technology; • The location of any compression equipment; • The location of any chemical storage facilities; and • The exit point of the CO_2 pipeline.	Figure 1A (for Scenario 1) / Figure 1B (for Scenario 2)
	Basic calculations, using the estimated volumes of CO_2 which will have to be processed, could usefully be included.	Section 4
Technical Assessment – Retrofitting and Integration		
Key Requirements of Paragraphs 30 to 31 of the CCR Guidance	The pre-feasibility level conceptual capture retrofit study should make clear which CO_2 capture technology is considered most appropriate for retrofit.	Section 4
	The pre-feasibility level conceptual capture retrofit study should provide sufficient detail to demonstrate that there are currently no known technical barriers to subsequent retrofit of this CO_2 capture technology.	Section 6
	The pre-feasibility level conceptual capture retrofit study should take into account the IEA Reference Document (IEAGHG 2007/4 "CO_2 Capture Ready Plants") Advisory Checklists. In terms of this Revised CCR Feasibility Study, the technical assessment is made against the information provided in Annex C ('Environment Agency Verification of CCS Readiness New Natural Gas Combined Cycle Power Station using Post Combustion Solvent Scrubbing') of the CCR Guidance.	Section 6
Annex C of the CCR Guidance: C1 (Design, Planning Permissions and Approvals)	A pre-feasibility level conceptual capture retrofit study should be supplied for assessment showing how the proposed features would make adding post-combustion CO_2 capture plant technology to the Proposed Development technically feasible.	Section 6
	An outline plot level plan for the post-combustion CO_2 capture plant technology at the Proposed Development should be provided.	Figure 1A (for Scenario 1) / Figure 1B (for Scenario 2)
Annex C of the CCR Guidance: C2 (Power Plant Location)	The work undertaken on the CO_2 transport and storage should be referenced.	Section 7 / Section 8
	The exit point of gases from the curtilage of the Proposed Development site should be provided. A statement on how this affects the configuration of the Proposed Development should be provided.	Section 8 / Figure 1A (for Scenario 1) / Figure 1B (for Scenario 2)

Requirement	***Description***	***Reference***
Annex C of the CCR Guidance: C3 (Space Requirements)	The CCR Guidance states that *"space will be required for the following:* *a) CO_2 capture equipment, including any flue gas pre-treatment and CO_2 drying and compression;* *b) Space for routing flue gas duct to the CO_2 capture equipment;* *c) Steam turbine island additions and modifications (e.g. space in steam turbine building for routing large low pressure steam pipe to amine scrubber unit);* *d) Extension and addition of balance of plant systems to cater for the additional requirements of the capture equipment;* *e) Additional vehicle movements (amine transport, etc.); and,* *f) Space allocation for storage and handling of amines and handling of CO_2 including space for infrastructure to transport CO_2 to the plant boundary."*	N / A
	All of the provisions of a) to f) should be implemented. A statement describing how the space allocations were determined and how they will be met is required.	Section 5 / Figure 1A (for Scenario 1) / Figure 1B (for Scenario 2)
Annex C of the CCR Guidance: C4 (Gas Turbine Operation with Increased Exhaust Pressure)	The CCR Guidance states that *"the gas turbine (and upstream ducting and heat recovery steam generator (HRSG)) must be able to operate with the increased back pressure imposed by the capture equipment, or alternatively space must be provided for a booster fan."*	N / A
	A statement giving the expected pressure drop required for current commercial CO_2 capture plant technology (together with a manufacturer's confirmation that the gas turbine can accommodate this) is required. In addition, for the expected pressure drop, a statement giving the anticipated effects on performance is required. Alternatively, a statement on the expected booster fan specification (and any associated space / installation requirements) is required.	Section 6.2
Annex C of the CCR Guidance: C5 (Flue Gas System)	The CCR Guidance states that *"space should be available for installing new duct work to enable interconnection of the existing flue gas system with the amine scrubbing plant and provisions in the duct work for tie-ins and addition of items, such as bypass dampers and isolation dampers, will be required as a minimum. If selective catalytic reduction (SCR) or other flue gas treatment is likely to be added at the time of retrofit then space for this should also be provided."*	N / A
	A statement describing the space and required flue gas system configuration (and how they would be implemented) is required.	Section 6.2

Requirement	***Description***	***Reference***
Annex C of the CCR Guidance: C6 (Steam Cycle)	A statement giving the steam pressure at the steam turbine IP / LP crossover (or other steam extraction point) is required. A statement on any post-retrofit equipment modifications / additions is required. A statement demonstrating that the steam cycle could be operated with CO_2 capture using solvent systems with a range of steam requirements is required. A statement estimating the energy penalty involved in steam extraction is required. A statement estimating the energy penalty involved in steam extraction (from a purpose built steam cycle) is required.	Section 6.2
Annex C of the CCR Guidance: C7 (Cooling Water System)	The CCR Guidance states *"the amine scrubber, flue gas cooler and CO_2 compression plant introduced for CO_2 capture increase the overall power plant cooling duty."*	N / A
	A statement of the estimated cooling water demands of the CO_2 capture plant technology (flows and temperatures) is required. A statement describing how the estimated cooling water demands of the CO_2 capture plant technology will be met is required. A statement describing how the cooling water will be supplied to the CO_2 capture plant technology is required. The chosen cooling water system should be justified.	Section 6.2
Annex C of the CCR Guidance: C8 (Compressed Air System)	The CCR Guidance states that *"the capture equipment addition will call for additional compressed air (both service and instrument air) requirements".*	N / A
	A statement of the estimated compressed air requirements of the CO_2 capture plant technology is required. A statement describing how the estimated compressed air requirements of the CO_2 capture plant technology will be met is required.	Section 6.2
Annex C of the CCR Guidance: C9 (Raw Water Pre-Treatment Plant)	The CCR Guidance states that *"space shall be considered in the raw water pre-treatment plant area to add additional raw water pre-treatment streams as required".*	N / A
	A statement of the estimated raw water pre-treatment requirements of the CO_2 capture plant technology is required. A statement describing how the estimated raw water pre-treatment requirements of the CO_2 capture plant technology will be met is required.	Section 6.2
Annex C of the CCR Guidance: C10 (Demineralisation / Desalination Plant)	The CCR Guidance states that *"a supply of reasonably pure water may be required to make up evaporative losses from the flue gas cooler and / or scrubber. Estimates of this water requirement should be made and space allocated for the necessary treatment plant (and an additional water source be identified if necessary".*	N / A
	A statement of the estimated demineralised / desalinated water requirements of the CO_2 capture plant technology is required. A statement describing how the estimated demineralised / desalinated water requirements of the CO_2 capture plant technology will be met is required.	Section 6.2

Requirement	***Description***	***Reference***
Annex C of the CCR Guidance: C11 (Waste Water Treatment Plant)	The CCR Guidance states that *"amine scrubbing plant along with flue gas coolers (if appropriate) provided for post-combustion CO_2 capture will result in generation of additional effluents".*	N / A
	A statement of the estimated waste water treatment needs of the CO_2 capture plant technology is required. A statement describing the expected post-treatment effluent quantity and composition is required. A statement describing the necessary space / other provisions due to the waste water treatment plant is required.	Section 6.2
Annex C of the CCR Guidance: C12 (Electrical)	The CCR Guidance states that *"the introduction of amine scrubber plant along with flue gas coolers, booster fans (if required), and CO_2 compression plant will lead to a number of additional electrical loads (e.g. pumps, compressors)".*	N / A
	A statement of the estimated electrical requirements of the CO_2 capture plant technology is required. A statement describing how the estimated electrical requirements of the CO_2 capture plant technology will be met is required. This should include the necessary space provisions which will be required.	Section 6.2
Annex C of the CCR Guidance: C13 (Plant Pipe Racks)	The CCR Guidance states that *"installation of additional pipework after retrofit with carbon capture will be required due to the use of a large quantity of LP steam in the amine scrubbing plant reboiler, return of condensate into the water-steam-condensate cycle, additional cooling water piping and possibly other plant modifications."*	N / A
	A statement describing the anticipated additional pipe work is required. A statement describing the necessary space / other provisions due to the plant pipe racks is required.	Section 6.2
Annex C of the CCR Guidance: C14 (Control and Instrumentation)	A statement describing the anticipated additional control and instrumentation equipment is required. A statement describing the necessary space / other provisions due to the additional control and instrumentation equipment is required.	Section 6.2
Annex C of the CCR Guidance: C15 (Plant Infrastructure)	The CCR Guidance states that *"space to widen roads and add new roads (to handle increased movement of transport vehicles), space to extend office buildings (to accommodate additional plant personnel after capture retrofit) and space to extend stores buildings are foreseeable. Consideration should also be given as to how, during a retrofit, vehicles and cranes will access the areas where new equipment will need to be erected".*	N / A
	A statement describing the anticipated additional plant infrastructure (new or widened roads/ extension of office buildings / etc) is required. A statement describing the necessary space / other provisions due to the additional plant infrastructure is required.	Section 6.2

Requirement	Description	Reference
Technical Assessment – CO_2 Storage Areas		
Key Requirements of Paragraph 42 of the CCR Guidance	Identify a possible storage area, including delineating the geological extent of that area, and identify within that area at least two oil or gas / gas condensate fields (or saline aquifers) listed in the range of geological formations identified as "viable" or "realistic" in the DTI Study 2006[5] for CO_2 storage.	Section 7 / Figure 3
	Provide a short summary (including an estimate) of the total volume of CO_2 likely to be captured and stored and an estimate of the potential total volume of CO_2 which could be stored in the area.	Section 7
Technical Assessment – CO_2 Transport		
Key Requirements of Paragraph 61 of the CCR Guidance	Provide sufficient detail to identify the preferred form and route for CO_2 transport on shore from the site exit point to the coastal transition point where the CO_2 goes offshore, including a map sufficiently large for the proposed route corridor to be clear.	Section 8 / Figure 2A / Figure 2B
	Provide sufficient detail to identify the preferred form and route for CO_2 transport off shore from the coastal transition point to the identified CO_2 storage area, including a map sufficiently large for the proposed route corridor to be clear.	Section 8 / Figure 3
	Demonstrate and confirm that there are no known barriers or unavoidable safety obstacles which exist within the identified on shore and off shore route corridors on the basis of current knowledge on CO_2 transport.	Section 8
	Suggest methods by which the environmental impacts on any unavoidable designated sites within the route corridor could be mitigated.	Section 8
Economic Assessment		
Requirement of Paragraph 64 of the CCR Guidance	Applicants should conduct a single economic assessment which encompasses retrofitting of CO_2 capture plant technology, CO_2 transport and CO_2 storage. The Government considers that this ensures that the assessments are a meaningful part of CCR Feasibility Studies. The economic assessment should demonstrate the full range of costs and benefits associated with the deployment of CO_2 capture plant technology, CO_2 transport and CO_2 storage to any given plant.	Section 9
Hazardous Substances Consent		
-	Determine the need, or otherwise, to apply for a Hazardous Substances Consent	Section 10

[5] 'Industrial Carbon Dioxide Emissions and Carbon Dioxide Storage Potential in the UK' Report No. COAL R308 DTI/Pub URN 06/2027 (DTI, October 2006).

2.4 The Structure of this Revised CCR Feasibility Study

2.4.1 Based on the above methodology, this Revised CCR Feasibility Study is structured as follows:

- ***Section 1***: A brief introduction, summarising the purpose of this Revised CCR Feasibility Study;
- ***Section 2***: The context (i.e. the need for a CCR Feasibility Study) and the assessment methodology that has been employed;
- ***Section 3***: A development description (covering the overall Proposed Development, the proposed SEE site, the CCR requirements for SEE associated with the Original Consent and an assessment of the requirement for SEE to be CCR);
- ***Section 4***: A description of the proposed CO_2 capture plant technology, including the design case for this Revised CCR Feasibility Study;
- ***Section 5***: The technical assessment regarding the CCS space requirement;
- ***Section 6***: The technical assessment regarding the retrofitting and integration of the CO_2 capture plant technology;
- ***Section 7***: The technical assessment regarding CO_2 storage areas;
- ***Section 8***: The technical assessment regarding CO_2 transport;
- ***Section 9***: The economic assessment;
- ***Section 10***: A discussion on the requirement for a Hazardous Substances Consent (HSC); and,
- ***Section 11***: The conclusions of this Revised CCR Feasibility Study.

Supporting information is provided in the Appendices.

3 DEVELOPMENT DESCRIPTION

3.1 SEE (i.e. The Proposed Development)

3.1.1 If the Original Consent is varied as per the Variation Application, SEE will provide up to 945 MW of power generation capacity. SEE will be capable of operating continuously for up to 35 years.

3.1.2 In providing up to 945 MW of power generation capacity, the Proposed Development will either comprise:

- Scenario 1: Up to 945 MW of CCGT units; or,
- Scenario 2: Up to 645 MW of CCGT units and less than 300 MW of Open Cycle Gas Turbine units.

3.1.3 In addition, if the Original Consent is varied as per the Variation Application, the commencement of the deadline for the Consent will be 5 years from the date of granting the variation. Similarly, the commencement deadline for the deemed planning permission will be 5 years from the date of granting the variation.

CCGT Unit

3.1.4 Under Scenario 1, there will be two CCGT units with a total rated electrical output of up to 945 MW. Under Scenario 2, there will be one CCGT unit with a rated electrical output of up to 645 MW.

3.1.5 Each CCGT unit will include a gas turbine, a HRSG, a steam turbine and associated equipment. The natural gas will be burnt in the combustion chamber of the gas turbine from which hot gases will expand through the turbine section to generate electricity. The hot exhaust gases still contain recoverable energy and will therefore be used in a HRSG to generate steam, which in turn is used to generate electricity via steam turbine equipment.

3.1.6 The steam exhausting the steam turbine equipment will pass to an Air Cooled Condenser (ACC) where it will be condensed. The resultant condensate will be returned to the HRSGs to continue the steam cycle.

3.1.7 The flue gases will be discharged via a dedicated stack.

3.1.8 The use of a combined gas and steam cycle increases the overall fuel efficiency of the generating station. As such, the CCGT unit will be capable of generation in combined cycle mode with an overall electrical generation efficiency between approximately 55 to 60 per cent based on the Lower Heating Value (LHV) of the fuel.

OCGT Units

3.1.9 Under Scenario 2, the OCGT unit(s) will have a total rated electrical output of less than 300 MW.

3.1.10 In essence, an OCGT unit comprises the prime driver of a CCGT unit, which is the gas turbine. As with an OCGT unit, the natural gas will be burnt in the combustion chamber of the gas turbine from where the hot gases will expand through the gas turbine to generate electricity.

3.1.11 As there is no steam cycle, there is no condensing of steam which has an associated cooling requirement. Furthermore, whilst auxiliary cooling is still required, this requirement is significantly lower than for that for a CCGT unit.

3.1.12 The hot exhaust gases are routed directly to a dedicated stack. The stack normally contains a silencer to reduce noise emissions. Due to the higher stack exit temperature, the stacks of OCGT units are generally shorter than those of CCGT units.

3.1.13 The OCGT units will have an electrical generation efficiency between approximately 33 to 43 per cent based on the LHV of the fuel.

3.2 The Proposed SEE Site

3.2.1 The proposed SEE site lies approximately 2 km to the north east of Spalding town centre. The Ordnance Survey (OS) Grid Reference of the centre of the SEE site is approximately 525950, 324950.

3.2.2 The location of the SEE site is shown outlined in red in Insert 3.1.

INSERT 3.1: LOCATION OF THE SEE SITE



3.2.3 The proposed SEE site is bounded by West Marsh Road to the east and by Vernatt's Drain to the west. The River Welland lies approximately 30 m to the east.

3.2.4 The proposed SEE site occupies a total area of approximately 14 ha, within which approximately 4.3 ha of land in the south of the proposed SEE site has been set aside by SEEL for the purposes of CCR.

3.3 Conditions associated with the Original Consent for SEE

3.3.1 Based on the Original CCR Feasibility Study and the Consolidated CCR Feasibility Study, there are Conditions within the Original Consent that require SEE to be CCR.

3.4 Requirement for the Proposed Development to be CCR

3.4.1 The Proposed Development will either comprise: CCGT units only; or, both CCGT and OCGT units. The requirement for these units to be CCR is considered separately in this sub-Section.

CCGT Unit

3.4.2 Under both Scenario 1 and Scenario 2, the CCGT unit(s) will be required to be CCR.

3.4.3 For Scenario 1, the Original CCR Feasibility Study and Consolidated CCR Feasibility Study determined the CCR Conditions were satisfied for up to 945 MW of CCGT units. The information from the Original CCR Feasibility Study and Consolidated CCR Feasibility Study is summarised in this Revised CCR Feasibility Study, and supplemented where necessary.

3.4.4 For Scenario 2, this Revised CCR Feasibility Study will determine whether the CCR Conditions are satisfied for up to 645 MW of CCGT units.

OCGT Unit(s)

3.4.5 The CCR Guidance states (at 'The Purpose and Applicability of the Guidance Document') that:

"*The CCR requirements* [or CCR conditions] *apply to applications for power stations with an electrical generating capacity at or over 300 MW and of a type covered by the* [LCPD, now IED]. *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".*

3.4.6 Therefore, under Scenario 2, as the OCGT unit(s) will have a total rated electrical output of less than 300 MW and they are a different generating unit type to the CCGT unit, the OCGT units should not be required to be CCR.

Summary of the Requirement for the Proposed Development to be CCR

3.4.7 In terms of the requirement for the Proposed Development to be CCR, it is considered that:

- The CCGT unit(s) will be required to be CCR. Further discussion is provided in the remainder of this Revised CCR Feasibility Study.
- The OCGT unit(s) will not be required to be CCR. No further discussion is provided in the remainder of this Revised CCR Feasibility Study.

4 PROPOSED CO_2 CAPTURE PLANT TECHNOLOGY

4.1 Current Understanding and Proposed CO_2 Capture Plant Technology

4.1.1 The current understanding is that the CO_2 capture plant / equipment will not be installed until CO_2 capture is either mandated or economically beneficial.

4.1.2 A number of CO_2 capture technologies currently exist, and at the time of eventual installation, it is highly probable that this number will have increased. However, similar to the Original CCR Feasibility Study and the Consolidated CCR Feasibility Study, this Revised CCR Feasibility Study focuses on the technology that is closest to commercial deployment in order to demonstrate CCR. Therefore, this Revised CCR Feasibility Study focuses on currently available technology rather than speculating on any future developments that may be available when the CO_2 capture plant is ultimately installed. Whilst many of these future developments are likely, it would be difficult to demonstrate that a combustion plant was CCR if it was dependent on uncertain and unproven future technical developments.

4.1.3 Therefore, similar to the Original CCR Feasibility Study and the Consolidated CCR Feasibility Study, CCR for the CCGT unit(s) has been assessed based on the assumption of the best currently available technology which for CO_2 capture from flue gases which is post-combustion CO_2 capture via chemical absorption using amine solvents. The amine solvents are typically based on monoethanolamine (MEA), diamine or sterically hindered amine.

4.1.4 This CO_2 capture plant technology may be regarded as commercially available, but has not yet been commercially proven for large-scale generating station applications. However, it is the belief of Ramboll that no technical barriers exist to extending existing experience to a scale appropriate to the Proposed Development.

Proposed CO_2 Capture Plant Technology

4.1.5 Post-combustion CO_2 capture consists a number of main process stages. These include:

- Flue gas cooling;
- CO_2 absorption;
- CO_2 stripping;
- Flue gas discharge;
- CO_2 discharge; and,
- CO_2 compression.

4.1.6 Post-combustion, the flue gases are cooled for processing in the CO_2 capture plant. Options for flue gas cooling include gas-gas re-heaters and direct cooling with water. After flue gas cooling, the flue gas is blown through an absorber column where it comes into contact with the liquid amine solvent.

4.1.7 In the absorber column, up to approximately 90 per cent of the CO_2 in the flue gas is chemically absorbed through acid-base neutralisation reactions with the amine solvent. This creates a CO_2 rich stream of liquid amine solvent. The CO_2 rich amine solvent is pumped out of the absorber column and is heated in a heat exchanger before entry into a stripper column.

4.1.8 In the stripper column, the CO_2 rich amine solvent is heated further by the condensation of steam in a re-boiler. As the amine can absorb less CO_2 at higher temperatures, upon heating, the amine solvent releases the CO_2 as a gas. The lean liquid amine solvent is pumped from the bottom of the stripper column, cooled in the heat exchanger and further cooled before re-entry to the absorber column.

4.1.9 The CO_2 gas, containing a large quantity of steam, exits at the top of the stripper column. It is cooled to remove the steam and compressed or liquefied for transport. Steam and water removed from the CO_2 stream are returned to the CO_2 capture plant.

4.1.10 This CO_2 capture plant technology can result in an end CO_2 purity of over 99 per cent based on the experience from similar technologies in the chemical processing industry.

CO_2 Capture Plant Technology Temperature

4.1.11 When CO_2 is in contact with the amine solvent, the CO_2 will react, leading to CO_2 being absorbed into the amine solvent. The efficiency of this CO_2 absorption (or capture) is driven by the fact that at lower temperatures more CO_2 will absorb into the amine solvent than at higher temperatures. Therefore, in principal, CO_2 is absorbed by cold amine and is released when the amine is heated.

4.1.12 In modern CO_2 capture processes, the stripper operates at a temperature of approximately 150°C. Temperatures higher than this will damage the amine. In theory, the absorber column can operate at any temperature below the stripper temperature. However, the larger the temperature difference between the two, the more CO_2 can be captured.

4.1.13 Indeed, a CO_2 capture process operating between an absorber column temperature of 50°C and a stripper temperature of 150°C would be able to capture approximately 85 per cent of the CO_2. A CO_2 capture process operating between an absorber column temperature of 35°C and a stripper temperature of 150°C would be able to capture approximately 90 per cent of the CO_2. However, it should be noted that these are indicative figures only and will depend on the various other parameters of the CO_2 capture process, such as: the particular amine used; the CO_2 capture plant technology temperature; the pressure in the absorber column and stripper; the residence time (i.e. the length of time the amine is in contact with the flue gas); and, the amount of other substances.

CO_2 Capture Plant Technology Requirements

4.1.14 CO_2 capture technologies require large amounts of power, for example to operate pumps and blowers and for the compression of the CO_2 product for onward transport in an efficient manner. A relatively small power demand is also required for the purposes of control and instrumentation.

4.1.15 Additionally, post-combustion CO_2 capture technology using amine solvent requires steam to regenerate the liquid amine solvent. In the case of an integrated CO_2 capture plant, this steam would otherwise be used in the steam cycle to generate power and hence the CO_2 capture equipment imposes a power penalty through its steam requirement.

4.1.16 This combination causes a significant reduction in the net electrical output and efficiency of the CCGT generating station. This has further impacts on the economics which are then required to be restored, for example through the implementation of CO_2 reduction revenues.

4.1.17 Additionally, substances such as nitrogen dioxide (NO_2), oxygen (O_2), particulate matter (PM) and sulphur dioxide (SO_2) have a detrimental effect on the CO_2 capture technology. The effects range from reduction in efficiency to the generation of solids (such as heat stable salts (HSS)) within the CO_2 capture plant. The HSS can cause problems (such as foaming) and therefore require filtration and addition of makeup liquid amine solvent.

4.1.18 Flue gases from CCGT units typically contain small amounts of NO_2 and approximately 14 per cent excess O_2. Whilst, NO_2 forms HSS when it reacts with the liquid amine solvent, when levels of NO_2 are below 10 ppm (approximately 21 mg/Nm^3) these can be effectively countered. Currently, EU Legislation requires the NO_x level in the flue gas to be reduced to below 50 mg/Nm^3. As NO_x typically contains less than 10 per cent NO_2, the level of NO_2 in the flue gas from CCGT units should not cause difficulty for the standard post-combustion CO_2 capture technology (using amine solvents). In addition, whilst O_2 also reduces the efficiency of the post-combustion CO_2 capture technology (using amine solvents), all calculations relating to the CO_2 capture in this Revised CCR Feasibility Study are based on flue gases from CCGT units. As such, the quantity of O_2 has already been taken into account.

4.2 CO_2 Output / Design Case for this Revised CCR Feasibility Study

4.2.1 The Proposed Development will either comprise: CCGT units only; or, both CCGT and OCGT units. However, as noted in Section 3.4 (Requirement for the Proposed Development to be CCR), only the CCGT unit(s) is / are required to be CCR.

4.2.2 Under Scenario 1, there will be two CCGT units with a total rated electrical output of up to 945 MW. Under Scenario 2, there will be one CCGT unit with a rated electrical output of up to 645 MW.

4.2.3 Under both Scenario 1 and Scenario 2, the only outputs of the modelling process of the CCGT units required for the sizing of the associated CO_2 capture plant / equipment are the CO_2 and flue gas flow rates, and the temperature of the flue gas[6].

4.2.4 Accordingly, modelling exercises have been conducted in order to determine the CO_2 and flue gas intensities for different CCGT unit technologies. These CO_2 and flue gas intensity factors have been used to estimate the maximum and average CO_2 and flue gas flow rates for the CCGT unit.

4.2.5 In addition to the above, there is an additional factor which needs to be considered which will influence the sizing of the CO_2 capture plant technology. This is related to the way steam is generated for the CO_2 capture plant technology. In brief:

- Option A: Steam for the CO_2 capture plant technology is taken from the steam cycle of the CCGT unit[7]; and
- Option B: Steam for the CO_2 capture plant technology is generated by auxiliary boilers[8].

4.2.6 Option A would impose greater requirements in terms of retrofitting when CO_2 capture plant technology is installed. For example, if a largely standard CCGT unit design is installed then, after retrofitting, the CCGT unit may be less efficient than had a 'non-standard capture-optimised' CCGT unit design been originally installed. However, a 'non-standard capture-optimised' CCGT unit design would likely incur an efficiency penalty during 'no capture' operation.

4.2.7 Option B would require minimal changes to be made in terms of retrofitting when CO_2 capture plant technology is eventually installed. However, additional fuel would be required for the auxiliary boilers which could in turn increase the size of the CO_2 capture plant technology if the auxiliary boilers flue gas were combined with the CCGT unit flue gases.

4.2.8 Whilst both Option A and Option B are potentially available for the CCGT unit, similar to the Original CCR Feasibility Study and the Consolidated CCR Feasibility Study, Option A is the main focus of this Revised CCR Feasibility Study.

4.2.9 Based on the implementation of Option A, it is expected that the CO_2 capture plant technology would be capable of capturing up to 90 per cent of the CO_2 in the CCGT unit flue gases. However, in reality, this value will be dependent on the CO_2 capture plant technology and the amount of process cooling available at the proposed SEE site.

Scenario 1

4.2.10 For Scenario 1, in the Original CCR Feasibility Study, CO_2 and flue gas intensity factors were modelled assuming a CCGT generating station configuration of two single shaft

[6] However, it should be noted that the temperature of the flue gas may be affected by some integration of the CCGT unit(s) with the CO_2 capture plant (i.e. if any flue gas cooling was implemented).
[7] Covers Option 1 (low pressure (LP) steam turbine extraction), Option 2 (high pressure (HP) and / or intermediate pressure (IP) steam turbine extraction) and Option 3 (HRSG extraction) from the Original CCR Feasibility Study.
[8] Covers Option 4 (external steam supply) from the Original CCR Feasibility Study.

CCGT units, comprising: two gas turbines; two steam turbines with a triple pressure re-heat steam cycle; and ACCs.

4.2.11 As the manufacturer had not been selected, modelling exercises were undertaken using a range of different gas turbine 'F' Class models which were commercially available and which would be suitable for the proposed SEE site. As this represents the gas turbine model which would be installed at the proposed SEE site under Scenario 1, the design case for Scenario 1 in this Revised CCR Feasibility Study is the same as that reported in the Original CCR Feasibility Study.

4.2.12 Therefore, for Scenario 1, the sizing of the CO_2 capture plant technology used the maximum CO_2 and flue gas intensity factors applied to the maximum theoretical electrical output of the CCGT unit, yielding the maximum possible CO_2 and flue gas flow rates. The CO_2 storage requirement was calculated using the average CO_2 flow rate.

4.2.13 Therefore, for Scenario 1, the sizing of the CO_2 capture plant technology / CO_2 storage requirement is based on the information presented in Table 4.1.

TABLE 4.1: SCENARIO 1 – SIZING FOR THE CO_2 CAPTURE PLANT TECHNOLOGY / CO_2 STORAGE REQUIREMENT[9]

Component		***Scenario 1 Up to 945 MW CCGT Units***
CO_2 Generated	kg/s	87
	t/h	313
Approx. CO_2 Captured (Assuming 90 per cent CO_2 capture rate)	kg/s	79
	t/h	283
	t/day	6800
CO_2 Stored (Assuming 90 per cent load factor of the CCGT unit)	Mt/year	2.2
Total CO_2 Stored (Assuming 35 years of CO_2 capture)	Mt	78.1

Scenario 2

4.2.14 For Scenario 2, CO_2 and flue gas intensity factors were modelled assuming a CCGT generating station configuration of one single shaft CCGT unit, comprising: one gas turbine; one steam turbine with a triple pressure re-heat steam cycle; and ACCs.

4.2.15 Again, as the manufacturer has not been selected, modelling exercises were undertaken using a range of different gas turbine 'H' Class models currently commercially available which would be suitable for the proposed SEE site.

4.2.16 The CO_2 and flue gas intensity factors (alongside the power ratios[10]) are shown in Table 4.2.

[9] Based on the information provided in the Original CCR Feasibility Study and the Consolidated CCR Feasibility Study.

[10] The power ratio is used to determine the maximum flow rates using the average flow rates. The power ratio is the difference between the total electrical output of the CCGT unit at typical site rated conditions (10°C) and the total electrical output of the CCGT unit at reduced atmospheric temperature conditions(5°C, selected to simulate the effect of anti-icing equipment). Accordingly, the power ratio is used to determine the maximum flow rates which could be expected from the CCGT unit under worst case conditions.

TABLE 4.2: CO_2 AND FLUE GAS INTENSITY FACTORS FOR DIFFERENT GAS TURBINE 'H' CLASS MODELS

	CO_2 Intensity (t/MWh)	*Flue Gas Intensity (t/MWhr)*	*Power Ratio*
Model A	0.34	5.3	1.02
Model B	0.34	5.0	1.02

4.2.17 Therefore, for Scenario 2, the sizing of the CO_2 capture plant technology was undertaken using the maximum values of the parameters in Table 4.2, as applied to the maximum theoretical electrical output of the CCGT unit, yielding the maximum possible CO_2 and flue gas flow rates. The CO_2 storage requirement was calculated using the average CO_2 flow rate.

4.2.18 Therefore, for Scenario 2, the sizing of the CO_2 capture plant technology and the CO_2 storage requirement is based on the information presented in Table 4.3.

TABLE 4.3: SCENARIO 2 – SIZING FOR THE CO_2 CAPTURE PLANT TECHNOLOGY / CO_2 STORAGE REQUIREMENT

Component		*Scenario 2 Up to 645 MW CCGT Unit (average / maximum)*
CO_2 Generated	kg/s	60.1 (61.3)
	t/h	216.5 (220.8)
Approx. CO_2 Captured (Assuming 90 per cent CO_2 capture rate)	kg/s	54.1 (55.2)
	t/h	194.8 (198.7)
	t/day	4676 (4769)
CO_2 Stored (Assuming 90 per cent load factor of the CCGT unit)	Mt/year	1.5
Total CO_2 Stored (Assuming 35 years of CO_2 capture)	Mt	53.8

Summary of Design Cases for this Revised CCR Feasibility Study

4.2.19 For operation under Option A, the CO_2 capture plant technology should be capable of handling a CO_2 flow rate of up to a maximum of:

- Approximately 313 t/h for Scenario 1; or,
- Approximately 221 t/h for Scenario 2.

4.2.20 The total annual throughput for the CO_2 capture plant technology will vary, and be dependent on the operational profile for the CCGT unit. However, with a 90 per cent lifetime capacity factor, the CO_2 storage requirement over a 35 year period, based on the average condition, would be:

- Approximately 78.1 Mt for Scenario 1; or,
- Approximately 53.8 Mt for Scenario 2.

5 TECHNICAL ASSESSMENT – CCS SPACE REQUIREMENT

5.1 CCR Guidance Requirements

5.1.1 The CCR Guidance notes that the aim of this technical assessment is to provide an outline plot level plan which is sufficiently detailed to show:

- The footprint of the Proposed Development;
- The location of the CO_2 capture plant technology;
- The location of any compression equipment;
- The location of any chemical storage facilities; and
- The exit point of the CO_2 pipeline.

5.1.2 To inform the preparation of this technical assessment, Table 1 of the CCR Guidance provides indicative CCS space requirements based on 500 MW (net) generating units. For CCGT units with post-combustion CO_2 capture, the original indicative CCS space requirement was 3.75 ha for 500 MW (original CCS space requirement). Subsequent to the publication of the CCR Guidance, this original indicative CCS space requirement was reviewed by Imperial College London[11]. The review by Imperial College London resulted in the correction of the indicative CCS space requirement for CCGT units with post-combustion CO_2 capture. This correction was a reduction of 36 per cent to 2.4 ha for 500 MW (reduced CCS space requirement). In addition, the review by Imperial College London further detailed additional scope for a further reduction in the indicative CCS space requirement by 50 per cent to 1.875 ha for 500 MW (further reduced CCS space requirement) considering technology advances and layout optimisation (e.g. assuming one carbon capture train per gas turbine unit train).

5.2 Technical Assessment

5.2.1 The existing CCS space available at the proposed SEE site is 4.3 ha. Table 5.1 presents a summary of these CCS space requirements in terms of the existing CCS space available at the proposed SEE site for both Scenario 1 and Scenario 2.

TABLE 5.1: SUMMARY OF CCS SPACE REQUIREMENTS, BASED ON CCR GUIDANCE AND IMPERIAL COLLEGE LONDON REVIEW

Parameter	*Scenario 1[12] Up to 945 MW CCGT Units*	*Scenario 2 Up to 645 MW CCGT Unit*
Existing CCS Space Available (ha)	4.3	
Original CCS Space Requirement[13] (ha)	6.8	4.9
As a proportion of space available %	158	113
Corrected CCS Space Requirement[14] (ha)	4.3	3.1
As a proportion of space available %	100	72
Further Reduced CCS Space Requirement[15] (ha)	3.4	2.4
As a proportion of space available %	78	56

[11] Review available at: http://www.decc.gov.uk/en/content/cms/meeting_energy/consents_planning/electricity/electricity.aspx
[12] Based on the information provided in the Original CCR Feasibility Study and the Consolidated CCR Feasibility Study.
[13] Based on 3.75 ha for a 500 MW (net) CCGT unit with post-combustion CO_2 capture.
[14] Based on 2.4 ha for a 500 MW (net) CCGT unit with post-combustion CO_2 capture.
[15] Based on 1.875 ha for a 500 MW (net) CCGT unit with post-combustion CO_2 capture.

5.2.2 Therefore, based on the use of Table 5.1, it can be seen that the existing CCS space available at the proposed SEE site is sufficient for both Scenario 1 and Scenario 2.

5.2.3 In addition, to meeting the CCS space requirement, the CCR Guidance also indicates that it is equally important to demonstrate that the available CCS space can physically accommodate the CO_2 capture plant technology.

5.2.4 In this regard, the outline plot level plan for Scenario 1 with CO_2 capture plant technology can be seen in Figure 1A. The outline plot level plan for Scenario 2 with CO_2 capture plant technology can be seen in Figure 1B. Figure 1A and Figure 1B also show the areas for the Proposed Development and the CCS space.

5.2.5 In terms of the CO_2 terminal point, this has been placed to match the most likely CO_2 transport option (i.e. via on shore pipeline). Therefore, for both Scenario 1 and Scenario 2, the CO_2 terminal point is located on the eastern boundary of the proposed SEE site[16]. Further information on the CO_2 transport option is provided in Section 8 of this Revised CCR Feasibility Study.

5.2.6 In terms of Scenario 1, Figure 1A shows that the actual CCS space estimated to be required is approximately 3.6 ha.

5.2.7 In terms of Scenario 2, Figure 1B shows that the actual CCS space estimated to be required is approximately 2.4 ha. In addition, under Scenario 2, as only 2.4 ha of the available 4.3 ha of CCS space is required for the CCGT unit, this leaves approximately 1.9 ha should SEEL wish to install CO_2 capture plant technology on the OCGT unit(s).

5.2.8 Therefore, the existing CCS space available at the proposed SEE site is sufficient for both Scenario 1 and Scenario 2.

5.3 Future Considerations

5.3.1 The CCS space requirements will be reviewed as part of the Status Reports[17]. These Status Reports will provide an opportunity for reassessment / review of the above, particularly regarding developments in CO_2 capture technologies.

[16] Note that this is a change from the CO_2 terminal point noted in the Original CCR Feasibility Study which was located on the southern boundary of the proposed SEE site.
[17] The first Status Report is required within 3 months of the commencement of commercial operation of SEE, and then every two years thereafter until SEE moves to retrofit CCS.

6 TECHNICAL ASSESSMENT – RETROFITTING AND INTEGRATION OF THE CO_2 CAPTURE PLANT TECHNOLOGY

6.1 Previous Findings of the Original CCR Feasibility Study and the Consolidated CCR Feasibility Study / CCR Guidance Requirements

6.1.1 The CCR Guidance notes that the aim of this technical assessment is to demonstrate that the CCGT unit(s) has / have been designed in such a way so as to enable subsequent retrofitting and integration of CO_2 capture equipment.

6.1.2 For both Scenario 1 and Scenario 2, the technical assessment is to be made against the information provided in Annex C ('Environment Agency Verification of CCS Readiness New Natural Gas Combined Cycle Power Station using Post Combustion Solvent Scrubbing') of the CCR Guidance. Annex C is provided in full in Appendix A.

6.2 Technical Assessment

6.2.1 As per the Original CCR Feasibility Study and the Consolidated CCR Feasibility Study, this technical assessment is based on an assumption of post-combustion capture via chemical absorption using an amine solvent, with the named solvent being MEA.

C1: Design, Planning Permissions and Approvals

6.2.2 This Revised CCR Feasibility Study shows that it is technically feasible to retrofit CO_2 capture plant technology to the CCGT unit(s) at the proposed SEE site.

6.2.3 For Scenario 1, an outline plot level plan is provided in Figure 1A. For Scenario 2, an outline plot level plan is provided in Figure 1B.

C2: Power Plant Location

6.2.4 This Revised CCR Feasibility Study shows that it is technically feasible to transport captured CO_2 (from either Scenario 1 or Scenario 2) to an existing offshore CO_2 storage area from the proposed SEE site.

6.2.5 In terms of the CO_2 terminal point, this has been placed to match the most likely CO_2 transport option (i.e. via on shore pipeline). Therefore, for both Scenario 1 and Scenario 2, the CO_2 terminal point is located on the eastern boundary of the proposed SEE site. Further information on the CO_2 transport option is provided in Section 8 of this Revised CCR Feasibility Study.

C3: Space Requirements

6.2.6 As required by the CCR Guidance, the following is specifically noted:

a) The provision of space for the main items of CO_2 capture plant technology (including flue gas pre-treatment and CO_2 drying and compression) is shown on the outline plot level plan in Figure 1A (for Scenario 1) and Figure 1B (for Scenario 2).

b) The provision of space for new duct work to allow interconnection of the existing flue gas system with the CO_2 capture plant technology is shown on the outline plot level plan in Figure 1A (for Scenario 1) and Figure 1B (for Scenario 2).

c) The provision of space for additional plant infrastructure (including roads in reasonable proximity to the key items of plant / equipment and the loading / unloading area and solvent storage) is shown on the outline plot level plan in Figure 1A (for Scenario 1) and Figure 1B (for Scenario 2).

d) The provision of space for loading and unloading solvent, and solvent storage is shown on the outline plot level plan in Figure 1A (for Scenario 1) and Figure 1B (for Scenario 2). In terms of the CO_2 terminal point, this has been placed to match the most likely CO_2 transport option (i.e. via on shore pipeline. Therefore, for both Scenario 1 and Scenario 2, the CO_2 terminal point is located on the eastern boundary of the proposed SEE site.

6.2.7 In combination with the above, it should be noted that the tender specifications for the CCGT unit(s) will include the following:

- The provision of space within the CCGT unit(s) for the future addition of flue gas off-take ducting, flue gas diversion mechanisms and access for retrofit / maintenance;
- The provision of space within the CCGT unit(s) for new duct work to allow interconnection of the existing flue gas system with the CO_2 capture plant technology;
- The provision of space within the CCGT unit(s) for additional pipe work / pipe work support (likely to be beneath the new duct work);
- The provision of space within the turbine hall of the CCGT unit(s) to allow for steam off-take, including space surrounding blanked-off off-take ports for addition of off-take pipe work (including isolation and bypass valves) and access for retrofit / maintenance;
- The provision of space within the CCGT unit(s) for the return pipe work / pipe work support (i.e. for condensate to the feedwater system); and,
- The provision of space to allow for additional raw water requirements, additional demineralised water requirements, additional waste water treatment requirements and additional compressed air requirements.

C4: Gas Turbine Operation with Increased Exhaust Pressure

6.2.8 Based on the introduction of CO_2 capture plant technology within each CCGT unit, the gas turbine (and upstream ducting / HRSG) may be subject to increased back pressure unless a booster fan is provided.

6.2.9 The provision of space for booster fans is shown on the outline plot level plan in Figure 1A (for Scenario 1) and Figure 1B (for Scenario 2). For each CCGT unit, the use of a booster fan will ensure that there is no pressure increase at the upstream CCGT unit stack, and therefore no increase in back pressure on the gas turbine.

6.2.10 For each CCGT unit, the booster fan will likely be constructed of stainless steel / coated carbon steel, and would be designed for a flue gas flow rate of approximately 3,415 t/hr.

6.2.11 Therefore, for both Scenario 1 and Scenario 2, it is considered that there are no foreseeable technical barriers to retrofitting and integration of the CO_2 capture plant technology in terms of gas turbine operation with increased exhaust pressure.

C5: Flue Gas System

6.2.12 For each CCGT unit, the provision of space for new duct work to allow interconnection of the existing flue gas system with the CO_2 capture plant technology is shown on the outline plot level plan in Figure 1A (for Scenario 1) and Figure 1B (for Scenario 2).

6.2.13 In addition, Selective Catalytic Reduction (SCR) is not deemed to be required for the CO_2 capture process assumed in this Revised CCR Feasibility Study as the LCPD (and IED) limits for NO_x will result in a flue gas containing a concentration of NO_2 that will not impact on the CO_2 capture process.

6.2.14 Therefore, for both Scenario 1 and Scenario 2, it is considered that there are no foreseeable technical barriers to retrofitting and integration of the CO_2 capture plant technology in terms of the flue gas system.

C6: Steam Cycle

6.2.15 As noted in Section 4 (Proposed CO_2 Capture Plant Technology), post-combustion CO_2 capture technology using amine solvent requires steam to regenerate the liquid amine solvent.

6.2.16 Vendors currently quote a range of condensing temperatures (and therefore pressures) for this steam. Vendors also quote a range of specific energy requirements for the regeneration of the amine solvent. Thus, the quantity of the steam which would be required for the CO_2 capture process would ultimately depend on the chosen process provider and the specific technology selected. Based on current technology, the steam required to be delivered to the CO_2 capture plant technology for the base case CO_2 capture process was modelled at:

- Steam Pressure – 4.5 bar a;
- Steam Flow – 224 t/h; and,
- Specific Energy Consumption – 2.7 GJ/t CO_2.

6.2.17 Based on Option A[18], the steam is extracted from the steam cycle of the CCGT unit(s). Whilst this integrated approach would ultimately require retrofitting of the CCGT unit(s), at this point it requires minimal design changes to the initial CCGT unit.

6.2.18 However, the final decision on the Option to implement and the location for the associated off-take port would come at the time of detailed design and installation of the CO_2 capture plant technology. This would depend upon, but not be restricted to, the following:

- Electricity market conditions;
- Capital cost of retrofitting; and,
- Age and condition of the CCGT unit (for example, it might be an opportune time to refurbish and / or upgrade the steam turbine).

6.2.19 In addition, extra steam might be required during some periods (e.g. if the CO_2 capture process calls for the storage of rich amine during periods of high electricity prices and stripping during periods of low electricity prices). These options have not been considered in the base case design. However it is recommended that these options are considered further during the detailed design of the steam system.

6.2.20 Illustrative overall performance results, based on Option A, are:

- For Scenario 1, a base case CCGT generating station with a net power output of 878 MW and an LHV efficiency of 57.2 per cent without CO_2 capture would correspond with a net power output of 808 MW with an LHV efficiency of 52.7 per cent with CO_2 capture (with steam supplied from CRH line).
- For Scenario 2, a base case CCGT generating station with a net power output of 584 MW and an LHV efficiency of 59.4 per cent without CO_2 capture would correspond with a net power output of 549 MW with an LHV efficiency of 55.8 per cent with CO_2 capture (with steam supplied from CRH line).

6.2.21 In addition to the above, steam would also be required during the reclaiming process, which would operate intermittently, concurrently with the CO_2 capture process. The steam required for reclaiming is typically at a higher pressure than that required for the CO_2 capture process and, for both Scenario 1 and Scenario 2, would require a flowrate of the order of 15 t/h. The steam cycle of the CCGT unit(s) should therefore be designed to also allow for the flow of this additional higher pressure steam.

6.2.22 Therefore, for both Scenario 1 and Scenario 2, it is considered that there are no foreseeable technical barriers to retrofitting and integration of the CO_2 capture plant technology in terms of the steam cycle of the CCGT unit(s), subject to detailed design being carried out.

[18] Covering Option 1 (LP steam turbine extraction), Option 2 (HP and / or IP steam turbine extraction) and Option 3 (HRSG extraction) discussed in the Original CCR Feasibility Study.

C7: Cooling Water System

6.2.23 An additional cooling duty would be imposed by the CO_2 capture plant technology. This additional cooling duty would be required for:

- Cooling the flue gases to absorber temperature (flue gas cooling);
- Cooling the lean amine before entry into the absorber (process cooling);
- Cooling the CO_2 and condensing of water in the CO_2 product before and between compression stages (inter-cooling); and,
- Cooling of the CO_2 capture ancillary plant / equipment.

6.2.24 Because of the high auxiliary cooling load of the CO_2 capture plant, water cooling would be a better option if available. Water cooling generally provides a lower temperature sink, and much smaller and less expensive heat exchangers. However, as it cannot be assumed that water cooling will be available in the future, air cooling has been assumed in this Revised CCR Feasibility Study.

6.2.25 The cooling requirements for the CO_2 capture plant technology have been estimated using information provided by vendors and from Thermoflex software modelling. A closed loop cooling liquid system (possible treated water or a glycol / water mixture) will transfer the heat between the cooling loads and the fin-fan coolers.

6.2.26 In terms of process cooling (which represents the highest cooling load), and based on the discussion in Section 4 (CO_2 capture plant technology temperatures), using air cooling it is not feasible to design the fin-fan coolers to maintain the absorber column temperature at 35°C throughout the year. With air cooling it would be more practical to cool the flue gases to 50°C which would still allow for a CO_2 capture rate of 85 per cent and would reduce the cooling load by approximately 5 per cent. However, for the purposes of this Revised CCR Feasibility Study the air cooling was sized such that the absorber column can operate at approximately 35°C at design average ambient conditions. The improved CO_2 capture rate during the winter will lead to a large offset of the poorer CO_2 capture rate during the summer.

6.2.27 Accordingly, with an absorber column inlet temperature of 35°C, the cooling load of the CO_2 capture plant technology is:

- Approximately 360 MJ/s for Scenario 1; or,
- Approximately 249 MJ/s for Scenario 2.

This agrees with information provided by vendors.

6.2.28 For the purposes of this Revised CCR Feasibility Study, it has been assumed that the cooling liquid is cooled in A-frame fin-fan coolers. The space requirement for the fin-fan coolers is approximately 16 m^2 per MJ/s of cooling duty. There would be no continuous make up water requirements for this cooling system.

6.2.29 Therefore, the space required for the additional cooling duty is estimated to be:

- Approximately 5,700 m^2 for Scenario 1; or,
- Approximately 3,900 m^2 for Scenario 2.

6.2.30 The provision of space for fin-fan coolers within the CCS space is shown on the outline plot level plan in Figure 1A (for Scenario 1) and Figure 1B (for Scenario 2).

6.2.31 Therefore, for both Scenario 1 and Scenario 2, it is considered that there are no foreseeable technical barriers to retrofitting and integration of the CO_2 capture plant technology in terms of additional cooling duty, subject to detailed design being carried out.

C8: Compressed Air System

6.2.32 Compressed air would be required for the instrument air system of the CO_2 capture plant. For both Scenario 1 and Scenario 2, this is estimated to be approximately 375 Nm^3/hr.

6.2.33 The provision of space for this additional compressed air requirement would be provided within the Compressed Air System at the Proposed Development. The requirement for the provision of this space will be included in the tender specification for the Proposed Development.

6.2.34 Therefore, for both Scenario 1 and Scenario 2, it is considered that there are no foreseeable technical barriers to retrofitting and integration of the CO_2 capture plant technology in terms of additional compressed air requirements, subject to detailed design being carried out.

C9: Raw Water Pre-Treatment Plant

6.2.35 For both Scenario 1 and Scenario 2, the additional water requirements for the CO_2 capture plant technology are estimated to be minimal. However, the provision of space for raw water storage and treatment will be provided with the Water / Firewater Storage Tank and the Water Treatment Plant at the Proposed Development. The requirement for the provision of this space will be included in the tender specifications for the Proposed Development.

6.2.36 Therefore, for both Scenario 1 and Scenario 2, it is considered that there are no foreseeable technical barriers to retrofitting and integration of the CO_2 capture plant technology in terms of additional raw water requirements, subject to detailed design being carried out.

C10: Demineralisation / Desalination Plant

6.2.37 Due to the absorber column design selected for this Revised CCR Feasibility Study, the CO_2 capture plant technology is a net producer of water and no evaporative losses would be realised from the flue gas of the CCGT unit(s).

6.2.38 However, additional demineralised water would be required to replace water removed during the amine reclaiming process. For both Scenario 1 and Scenario 2, this is estimated to be approximately 0.5 m^3/hr.

6.2.39 The provision of space for this additional demineralised water requirement will be provided within the Water Treatment Plant at the Proposed Development. The requirement for the provision of this space will be included in the tender specifications for the Proposed Development.

6.2.40 Therefore, for both Scenario 1 and Scenario 2, it is considered that there are no foreseeable technical barriers to retrofitting and integration of the CO_2 capture plant technology in terms of additional demineralised water requirements, subject to detailed design being carried out.

C11: Waste Water Treatment Plant

6.2.41 For both Scenario 1 and Scenario 2, it is currently anticipated that the waste water generated by the CO_2 capture plant technology would be treated in the Water Treatment Plant for the Proposed Development. Therefore, the provision of space for any additional waste water generated will be provided within the Water Treatment Plant at the Proposed Development. The requirement for the provision of this space will be included in the tender specifications for the Proposed Development. All waste water will be treated to control concentrations of various compounds to within the limits prescribed by an Environmental Permit.

6.2.42 In addition, for both Scenario 1 and Scenario 2, the final design of the CO_2 capture plant technology will include provisions for surface water drainage, contaminated surface water drainage (which will initially drain to oil interceptors) and process water drainage. .

6.2.43 Therefore, for both Scenario 1 and Scenario 2, it is considered that there are no foreseeable technical barriers to retrofitting and integration of the CO_2 capture plant technology in terms of additional waste water, subject to detailed design being carried out.

C12: Electrical

6.2.44 For both Scenario 1 and Scenario 2, the gas turbine and steam turbine generators, and step-up transformers, will be sized for maximum generator output. Similarly, the outgoing high voltage (HV) electrical connection to National Grid Electricity Transmission System (and associated systems) will also be designed for the maximum electrical power output.

6.2.45 However, the retrofitting and integration of CO_2 capture plant technology will lead to an estimated electrical requirement of:

- Approximately 60 MW for Scenario 1; or
- Approximately 40 MW for Scenario 2.

6.2.46 At this stage it is suggested that this is met by a reduction in the electrical output from the CCGT unit(s) to the National Grid Electricity Transmission System using auxiliary transformers.

6.2.47 For both Scenario 1 and Scenario 2, the provision of space for additional electrical plant / equipment associated with specific power plant / CO_2 capture plant items (i.e. pumps / fans) will be provided within the respective plant item areas. This additional electrical plant / equipment is small in size and could be readily accommodated.

6.2.48 Therefore, for both Scenario 1 and Scenario 2, it is considered that there are no foreseeable technical barriers to retrofitting and integration of the CO_2 capture plant technology in terms of electrical, subject to detailed design being carried out.

C13: Plant Pipe Racks

6.2.49 The provision of space for plant pipe racks within the CCS space is shown on the outline plot level plan in Figure 1A (for Scenario 1) and Figure 1B (for Scenario 2). These plant pipe racks allow for the installation of additional pipe work between the CCGT unit(s) and the CO_2 capture plant technology. The provision of space for plant pipe racks on the CCGT unit will be included in the tender specifications for the Proposed Development.

Therefore, for both Scenario 1 and Scenario 2, it is considered that there are no foreseeable technical barriers to retrofitting and integration of the CO_2 capture plant technology in terms of plant pipe racks, subject to detailed design being carried out.

C14: Control and Instrumentation

6.2.50 For both Scenario 1 and Scenario 2, the control and instrumentation system for the CO_2 capture plant technology is anticipated to be incorporated into the Distributed Control System (DCS) of the Proposed Development (i.e. would be within the Control Building at the Proposed Development). Therefore, the provision of space for the control and instrumentation system will comprise that to be used for the routing of cabling to / from and the installation of equipment within the Control Building at the Proposed Development. The requirement for the provision of this space will be included in the tender specifications for the Proposed Development.

6.2.51 Therefore, for both Scenario 1 and Scenario 2, it is considered that there are no foreseeable technical barriers to retrofitting and integration of the CO_2 capture plant technology in terms of control and instrumentation, subject to detailed design being carried out.

C15: Plant Infrastructure

6.2.52 The provision of space for plant infrastructure (i.e. the CO_2 capture plant technology) is shown on the outline plot level plan in Figure 1A (for Scenario 1) and Figure 1B (for Scenario 2). In addition, the design basis for the Proposed Development ensures that

offices and stores are sufficiently sized for the additional requirements of the CO_2 capture plant technology.

6.2.53 Furthermore, the proposed SEE site is accessible from the existing road network, and is not considered to have any access constraints which could impede future construction / operational activities.

6.2.54 Therefore, for both Scenario 1 and Scenario 2, it is considered that there are no foreseeable technical barriers to retrofitting and integration of the CO_2 capture plant technology in terms of plant infrastructure.

6.3 Future Considerations

6.3.1 The requirements for retrofitting and integration of CCS will be reviewed as part of the Status Reports. These Status Reports will provide an opportunity for reassessment / review of the above, particularly regarding developments in CO_2 capture technologies.

7 TECHNICAL ASSESSMENT – CO_2 STORAGE AREAS

7.1 CCR Guidance Requirements

7.1.1 The CCR Guidance notes that the aim of this technical assessment is to:

- Identify a possible storage area, including delineating the geological extent of that area, and identify within that area at least two oil or gas / gas condensate fields (or saline aquifers) listed in the range of geological formations identified as "viable" or "realistic" in the DTI Study 2006[19] for CO_2 storage; and,
- Provide a short summary (including an estimate) of the total volume of CO_2 likely to be captured and stored and an estimate of the potential total volume of CO_2 which could be stored in the area.

7.2 Technical Assessment

7.2.1 In order to determine any CO_2 storage areas, it is necessary to have an idea of the CO_2 storage requirements of SEE. In line with the calculations summarised in Table 4.1 (for Scenario 1) and Table 4.3 (for Scenario 2), the CO_2 storage requirements over a 35 year period would be:

- Approximately 78.1 Mt of CO_2 for Scenario 1; or
- Approximately 53.8 Mt of CO_2 for Scenario 2.

7.2.2 Based on DECC's 'CO_2 Storage Sites: Areas Identified for Potential Usage in CCR Reports'[20], it was identified that the Proposed Development would use the West Sole gas field to satisfy this CO_2 storage requirement.

7.2.3 Accordingly, the percentage CO_2 storage requirement against the CO_2 storage capacity of the West Sole gas field is presented in Table 7.1.

TABLE 7.1: PERCENTAGE CO_2 STORAGE REQUIREMENT OF THE PROPOSED DEVELOPMENT AGAINST THE CO_2 STORAGE CAPACITY OF THE WEST SOLE GAS FIELD

	CO_2 Storage Requirement	***% of the CO_2 Storage Capacity of the West Sole Gas Field (Overall Capacity 143 Mt CO_2)***
Scenario 1	78.1 Mt	54.6%
Scenario 2	53.8 Mt	37.6%

7.2.4 Accordingly, it is proposed that the preferred CO_2 storage area for the Proposed Development remains the West Sole gas field as this will satisfy the CO_2 storage requirement of both Scenario 1 and Scenario 2, and does not have any other identified potential users.

7.2.5 However, it is noted that in the future it is likely that there may be competing interest for identified CO_2 storage areas as other CCS projects become operational. However, there are clearly a large number of additional CO_2 storage areas which exist in the same region that are capable of meeting the CO_2 storage requirement of the CCGT unit.

7.2.6 Indeed, Table 7.2 lists all the CO_2 storage areas available in the same region (the SNS) that are capable of meeting the CO_2 storage requirement of the Proposed Development which have been identified in the CCR Guidance[21].

[19] 'Industrial Carbon Dioxide Emissions and Carbon Dioxide Storage Potential in the UK' Report No. COAL R308 DTI/Pub URN 06/2027 (DTI, October 2006).
[20] Available at: https://www.og.decc.gov.uk/EIP/pages/c02.htm

TABLE 7.2: CO_2 STORAGE AREAS AVAILABLE IN THE SNS REGION

Field Name	***CO_2 Storage Capacity (Mt of CO_2)***
Amethyst	63
Barque	108
Clipper	60
Galleon	137
Hewett L Bunter	237
Hewett U Bunter	122
Indefatigable	357
Leman	1203
Ravenspurn North	93
V Fields	143
Viking	221
Windermere	143
Total	**2887**

7.2.7 Therefore, whilst the decision as to which specific CO_2 storage area to use will not be made until eventual implementation of the CO_2 capture plant technology, Table 7.2 shows that the potential CO_2 storage areas in the region (which are capable of meeting the CO_2 storage requirement of both Scenario 1 and Scenario 2) have a total CO_2 storage capacity in excess of 2887 Mt of CO_2. Under Scenario 1, the Proposed Development would require less than 2.7 per cent of this CO_2 storage requirement over its 35 year lifetime. Under Scenario 2, the Proposed Development would require less than 2.0 per cent of this CO_2 storage capacity over its 35 year lifetime.

7.2.8 In addition, there may be an available 'CO_2 Network' in the region such that CO_2 from the Proposed Development, and other CO_2 capture combustion plants in the region, would be delivered to a 'central hub'. From this 'central hub', the CO_2 would be delivered to a number of different CO_2 storage areas.

7.3 Future Considerations

7.3.1 The proposed CO_2 storage area will be reviewed as part of the Status Reports.

[21] Other CO_2 storage areas with smaller CO_2 storage capacities than that required to satisfy the CO_2 storage requirements of the CCGT unit are also identified in the CCR Guidance. However, they have not been listed here.

8 TECHNICAL ASSESSMENT – CO_2 TRANSPORT

8.1 Previous Findings of the Original CCR Feasibility Study and the Consolidated CCR Feasibility Study / CCR Guidance Requirements

8.1.1 In the Original CCR Feasibility Study, it was identified that there are various options for CO_2 transport. These included: pipeline; road; rail; and, shipping.

8.1.2 The CCR Guidance states (at paragraph 43) that:

"*The onshore transport of CO_2 is expected to be by pipeline, given the large volumes which will be captured at a power station of the size covered by the CCR requirement. Transport offshore to the storage site may be by pipeline or ship".*

8.1.3 In addition, the CCR Guidance notes that the aim of this technical assessment is to demonstrate:

- (at paragraph 44) "*that a feasible route exists from the site to the* [CO_2] *storage area"*;
- (also at paragraph 44) that "*for the first 10 km surrounding the power station* […] *identify a favoured route for their pipeline within a 1 km wide corridor"*;
- (at paragraph 46) that "*after the first 10 km from the power station* […] *identify a 10 km wide corridor to the point(s) on the coast where they envisage either a pipeline going offshore or CO_2 going on board a ship"*; and,
- (at paragraph 52) "*that a feasible route from land to sea exists".*

8.1.4 The Original CCR Feasibility Study noted that further investigation of pipeline routes be postponed until the CCR requirements were known. Therefore, this technical assessment has been undertaken to satisfy the above required demonstrations.

8.2 Technical Assessment

8.2.1 This Section presents the technical assessment on CO_2 transport for both Scenario 1 and Scenario 2.

Considerations at the Proposed SEE Site

8.2.2 In terms of the CO_2 terminal point, this has been placed to match the most likely CO_2 transport option (i.e. via on shore pipeline). Therefore the CO_2 terminal point is located on the eastern boundary of the proposed SEE site. The CO_2 terminal point is shown on the outline plot level plan for the CCGT unit CO_2 capture plant technology in Figure 1A for Scenario 1 and Figure 1B for Scenario 2.

CO_2 Transport On shore

8.2.3 It is proposed that CO_2 transport on shore, from the proposed SEE site to the coastal transition point, is via an on shore CO_2 pipeline. The proposed on shore CO_2 pipeline route corridor is shown on Figure 2A and Figure 2B which illustrate a 1 km wide corridor for the first 10 km and a 10 km wide corridor thereafter.

8.2.4 With a view to minimising any potential environmental / health / safety impacts, it has been considered desirable to follow the route of existing pipeline routes wherever possible. Accordingly, the on shore CO_2 pipeline route corridors would run from the proposed SEE site, along a similar route to that of the proposed SEE underground gas pipeline, to link in with the existing National Grid National Gas Transmission System pipeline routes. The proposed SEE gas pipeline and existing National Grid National Gas Transmission System pipeline routes are also shown on Figure 2A and Figure 2B.

8.2.5 The on shore CO_2 pipeline route corridor would run north east from the proposed SEE site to Wragg Marsh to link in with the existing National Grid National Gas Transmission System pipeline routes. Upon meeting the National Grid National Gas Transmission System pipeline routes, the on shore CO_2 pipeline route corridor would run towards the

Theddlethorpe Gas Terminal (which is the proposed coastal transition point). The length of the proposed on shore CO_2 pipeline route would be approximately 90 km.

CO_2 Transport Off shore

8.2.6 It is proposed that CO_2 transport off shore, from the coastal transition point to the CO_2 storage area, is via an off shore CO_2 pipeline. The proposed off shore CO_2 pipeline route corridors are shown on Figure 3.

8.2.7 Again, with a view to minimising any potential environmental / health / safety impacts, it has been considered desirable to follow the route of existing pipeline routes wherever possible.

CO_2 Transport Barriers

CO_2 Transport On shore

8.2.8 In terms of on shore barriers, the on shore CO_2 pipeline route corridor has followed the route of existing National Grid National Gas Transmission System pipeline routes (wherever feasible). In doing so it is considered that the on shore CO_2 pipeline route corridor has been designed in line with the following guiding principles:

- Routed away from habitation (and any potential future developments) as much as possible to reduce the impacts of construction and operation;
- Routed close to existing hydrocarbon pipelines to minimise proliferation of pipelines; and,
- Route close to existing hydrocarbon pipelines to minimise the number of different landowners / tenants affected.

8.2.9 Accordingly, it is considered that there are no known barriers or unavoidable safety obstacles which exist within the identified on shore CO_2 pipeline route corridor.

8.2.10 However, it may be that the on shore CO_2 pipeline would likely to run through or near to areas with environmental constraints. Typically these include: Special Protection Areas (SPAs); Special Areas of Conservation (SACs); RAMSAR sites (especially around coastal areas); Sites of Special Scientific Interest (SSSI); and, Scheduled Monuments. If (after further CO_2 pipeline routing), it is not possible to navigate / avoid these areas, trenchless construction techniques (i.e. auger boring / Horizontal Directional Drilling (HDD)) may be used to minimise any environmental impacts and meet any relevant regulations. Furthermore, the impact on protected habitats and species may be minimised by planning the construction of the CO_2 pipeline around breeding seasons and migrating patterns.

CO_2 Transport Off shore

8.2.11 In terms of off shore barriers, the off shore CO_2 pipeline route corridor has followed the route of existing pipeline routes (wherever possible). In doing so it is considered that the off shore CO_2 pipeline route corridor has been designed in line with the above guiding principles.

8.2.12 Accordingly, it is considered that there are no known barriers or unavoidable safety obstacles which exist within the identified off shore CO_2 pipeline route corridor.

8.2.13 However, it may be that the off shore CO_2 pipeline would likely to run through or near to areas with environmental constraints. Typically these include: passing through environmentally sensitive wetlands; off shore wind farm sites and associated cabling; dredging areas; existing pipeline infrastructures; disposal sites; and, shipping lanes.

8.2.14 In terms of environmentally sensitive wetlands, and to minimise any environmental impacts at points close to shore, specialist trenching and laying construction techniques would be used at low tide or low current periods. Where any environmental impacts are deemed to be unacceptable, trenchless construction techniques may be used. Furthermore, the impact on protected habitats and species may be minimised by

planning the construction of the CO_2 pipeline around breeding seasons and migrating patterns.

8.2.15 In terms of off shore wind farm sites and associated cabling, dredging areas, existing pipeline infrastructures and disposal sites, navigation is considered feasible. Indeed, it is currently considered that there is sufficient space between such sites to allow for the installation of an off shore CO_2 pipeline within the specified CO_2 pipeline route corridor.

8.2.16 In terms of shipping lanes, it is not anticipated that these lanes would be a significant barrier to an off shore CO_2 pipeline as the off shore CO_2 pipeline would run along the seabed at a sufficient depth to allow ships to pass freely over. In addition, it is worth noting the relevant knowledge, skills, experience and techniques that exist in the UK Natural Gas and Oil Industries for this to be a feasible option.

8.2.17 In addition, whilst not discussed in detail in this Revised CCR Feasibility Study, shipping of CO_2 (via road and rail on shore / via ship off shore) may also be considered in the future. However, since there are a wider range of uncertainties surrounding this option (such as temporary storage on shore, consenting requirements and land use issues) it is not considered further. As the uncertainties surrounding this option decrease, this option may be considered in the future as a viable transport option, and therefore will be reviewed.

CO_2 Transport Considerations

Pipeline Route Selection Considerations

8.2.18 Ultimately, it is unlikely that the shortest CO_2 pipeline route from the proposed SEE site to the CO_2 storage area will be the most suitable, and indeed the design of any CO_2 pipeline (or CO_2 pipeline network) will take a number of factors into consideration. These will include:

- Technical Factors, comprising:
  - Pipeline fluid and proposed operating conditions;
  - Likely access;
  - Likely requirements for construction, commissioning, operation, maintenance and inspection;
  - Consideration of safety (both public and personnel); and,
  - Consideration of security requirements.
- Planning Factors;
- Land Factors, comprising:
  - Land use (historical, current and future);
  - Any agricultural practices;
  - Any third party activities; and,
  - The location of the existing facilities and services (including transport and utilities).
- Environmental Factors, comprising:
  - Consideration of the location of Statutory Designated Sites; and,
  - Geological conditions (including topographical, geotechnical and hydrographical conditions).

8.2.19 Therefore, in order to further develop the CO_2 pipeline route from the proposed SEE site to the CO_2 storage area, it is likely that three phases of routing would be adopted. The phases of routing would be:

Phase 1) CO_2 pipeline route corridor selection

Phase 2) CO_2 pipeline route corridor investigation and consultation

Phase 3) Design and approval of the final CO_2 pipeline route

Safety Considerations

8.2.20 As noted in the CCR Guidance, it may be that (during operation with CO_2 capture, compression, transportation and storage) dense phase CO_2 would be present on-site and within the CO_2 pipeline once the CO_2 is compressed in preparation for transport. Whilst dense phase CO_2 is not currently classified as hazardous, it is now recognised that an accidental release of large quantities of dense phase CO_2 could result in a major accident. As such, there is currently extensive on-going research into the hazard potential of dense phase CO_2. The results of this on-going research will inform future decisions on CO_2 and whether a classification review (i.e. dense phase CO_2 is classified as hazardous) is necessary.

8.2.21 As a result, in terms of CO_2 pipeline routes / transport, the mechanisms, hazards, consequences and probabilities of CO_2 pipeline failure need to be understood so that safe design, commissioning and operation can be ensured. Accordingly, a precautionary approach has been taken in respect of dense phase CO_2 to ensure no foreseeable barriers exist along the proposed CO_2 pipeline route.

8.2.22 In line with the precautionary approach, the Health and Safety Executive (HSE) require that dense phase CO_2 is treated as a *"dangerous fluid"* under the Pipeline Safety Regulations 1996.

8.2.23 In addition, a dense phase CO_2 pipeline would be treated as a *"Major Accident Hazard Pipeline"* under the Pipeline Safety Regulations 1996. As such, the following documents / considerations would need to be produced / included for the ultimate design, commissioning and operation of a dense phase CO2 pipeline:

- A 'Major Accident Prevention Plan;
- A 'Pipeline Safety Evaluation and Technical Safety Risk Assessment', including failure mechanisms, probability and consequence of failure. Mitigation measures will also be detailed;
- An 'Asphyxiation Risk Assessment';
- An 'Operations, Maintenance and Emergency Response Policy', including procedures and work instructions for:
  - The safe control of operations; and,
  - The safe working in the vicinity of a high pressure pipeline.
- Emergency shutdown valves to be fitted to the CO_2 pipeline; and
- South Holland District Council (as the relevant local authority) to be notified and South Holland District Council to have prepared an 'Emergency Plan'.

8.2.24 However, it is not necessary to address these items at this stage due to the uncertainty surrounding the final CO_2 pipeline route and the classification of dense phase CO_2. In this regard, SEEL will hold informal discussions with South Holland District Council (the local planning authority) about the potential issues surrounding dense phase CO_2, including the implications of CO_2 transport via a dense phase CO_2 pipeline. These informal discussions will continue until further information concerning the classification of dense phase CO_2 is available. This will ensure that there is early identification of any potential implications on South Holland District Council's long term plan for the area. However, at this stage is it felt that no formal discussions or preparations are necessary.

8.3 Future Considerations

8.3.1 The proposed CO_2 transport options will be reviewed as part of the Status Reports.

9 ECONOMIC ASSESSMENT

9.1 CCR Guidance Requirements

9.1.1 The CCR Guidance states (at paragraph 7) that, amongst other things, applicants will be required to demonstrate: *"the likelihood that it will be economically feasible within the power station's lifetime to link it to the full CCS chain, covering retrofitting of carbon capture equipment, transport and storage"*.

9.1.2 Furthermore, the CCR Guidance states (at paragraph 63) that: *"Directive 2009/31/EC requires applicants to carry out an assessment of the economic feasibility of retrofitting and transport. Recital 47 states that "The economic feasibility of the transport and retrofitting should be assessed taking into account the anticipated costs of avoided CO_2 for the particular local conditions in case of retrofitting and the anticipated costs of CO_2 allowances in the Community. The projections should be based on the latest evidence; review of technical options and uncertainty analysis should also be undertaken""*.

9.1.3 Therefore, the CCR Guidance requirements are to demonstrate the full range of costs and benefits associated with the deployment of CO_2 capture plant technology, CO_2 transport and CO_2 storage to any given plant.

9.2 Introduction

9.2.1 This Section presents the results of the economic assessment which investigates the feasibility of incorporating CO_2 capture technology into the Proposed Development. The economic assessment tests a number of key industry and market sensitivities, and is consistent with the assessments completed for previous CCR Feasibility Studies.

9.2.2 In terms of undertaking an economic assessment the CCR Guidance notes (at paragraph 68) that a wide range of parameters are likely to be included, including:

- Assumed £ / € exchange rate;
- Future fuel prices (both absolute and relative to other fuels);
- Electricity price levels;
- Carbon price;
- Power output with / without CO_2 capture, transport and storage;
- Lifetime load factor;
- CO_2 emitted with / without CO_2 capture, transport and storage;
- Estimations of costs of retrofitting CO_2 capture equipment (construction and operation);
- Estimations of costs of transport (construction and operation);
- Estimations of costs of storage (permitting and operation); and,
- Reasonable estimations of when these costs would be incurred.

9.2.3 With regards to these parameters, it should be noted that the estimations of costs used in this economic assessment are based on those for CO_2 capture plant technology, CO_2 transport and CO_2 storage based on technology available in 2014 / 2015. These costs are expected to reduce in time, bearing in mind the recent and likely future developments in technology.

9.3 Approach / Assessment Methodology

9.3.1 For both Scenario 1 and Scenario 2, to investigate the economic feasibility of the Proposed Development with the addition of CO_2 capture equipment, an economic model has been developed to calculate the lifetime cost of electricity, expressed in p/kWh, over an assumed 35 year economic lifetime of the Proposed Development.

9.3.2 As required by the CCR Guidance, the economic model encompasses the likely costs of CO_2 capture equipment, transport and storage. However, the effects of taxation have not been considered in the economic model.

9.3.3 Using the economic model, for both Scenario 1 and Scenario 2, the economic feasibility of the Proposed Development was assessed by varying the price of EU Allowances under the EU Emissions Trading Scheme (EU ETS) / UK Carbon Floor Price (carbon price) whilst the remaining parameters remained constant. Carbon prices ranged from €0/t CO_2 to €200/t CO_2. This allowed for the identification of the carbon price where SEE with CO_2 capture equipment, transport and storage would become economically feasible.

9.3.4 The approach / assessment methodology is shown in Insert 9.1.

INSERT 9.1: ECONOMIC ASSESSMENT METHODOLOGY

Step 1

- The economic model calculates the cost of electricity generation (p/kWh) over the lifetime of the proposed development without the addition of CO_2 capture technology, transport and storage.
- This assumes that allowances must be purchased for 100 per cent of the residual CO_2 emissions.

Step 2

- The economic model calculates the costs of electricity generation (p/kWh) over the lifetime of the proposed development with the addition of CO_2 capture technology, transport and storage (for a number of different Scenarios).
- Again, this assumes that allowances must be purchased for 100 per cent of the residual CO_2 emissions.

Step 3

- The Base Case assumptions are subjected to a sensitivity analysis to identify potential ranges for the carbon price for the different Scenarios.

Step 4

- The range of costs of electricity generation (p/kWh) for the different Scenarios are plotted graphically to present the range of carbon prices within which retrofitting of CO_2 capture technology, transport and storage would be economically feasible.

9.4 Estimations / Assumptions

9.4.1 The main estimations and assumptions made in the economic assessment are detailed in Table 9.1.

TABLE 9.1: BASE CASE ESTIMATIONS / ASSUMPTIONS

Variable	***Assumption***
Assumed First Year of Operation	2020
£:€ Exchange Rate[22]	1.321
Nominal Discount Rate	10%
Gas Price	60.3 p/therm[23]
Carbon Allocations	None for Power Sector – Full Purchase
Scenario 1: Power Output Impact of CO_2 Capture, Transportation and Storage	
Net Power Output of SEE	878 MW
Net Power Output of SEE with steam extraction for the CO_2 capture technology	808 MW
Lifetime load factor of SEE	75%
CO_2 emitted by SEE before fitting CO_2 capture technology	Approximately 357 kg/MWh
CO_2 emitted by SEE after fitting CO_2 capture technology	Approximately 39 kg/MWh
Scenario 2: Power Output Impact of Carbon Capture, Transportation and Storage :	
Net Power Output of SEE	584 MW
Net Power Output of SEE with steam extraction for the CO_2 capture technology	494 MW
Lifetime load factor of SEE	75%
CO_2 emitted by SEE before fitting CO_2 capture technology	Approximately 341 kg/MWh
CO_2 emitted by SEE after fitting CO_2 capture technology	Approximately 40 kg/MWh

9.5 Economic Assessment Scenarios

9.5.1 For both Scenario 1 and Scenario 2, the economic model runs three possible scenarios relating to the readiness level of the CO_2 capture technology and the possible transport and storage infrastructure options. These three possible scenarios are:

- Scenario A: First of a Kind Plant, with dedicated Transport and Storage

  Scenario A assumes that the CCGT unit(s) will be the first to be fitted with CO_2 capture equipment, transport and storage amongst the CCR CCGT generating station fleet. This means that the construction cost will be relatively high because of the lack of experience.

[22] Exchange rate taken on 3 February, 2015.
[23] Source: Central Scenario of "DECC Fossil Fuel Price Projections" (DECC, September 2014).

In addition, within Scenario A, it is assumed that all of the onshore and offshore transport and storage infrastructure will be based on new assets. This infrastructure will be sized to SEE and would be 'dedicated'.

- Scenario B: First of a Kind Plant, with dedicated Transport and Reused Storage

  Similar to Scenario A, Scenario B assumes that the CCGT unit(s) will be the first to be fitted with CO_2 capture equipment, transport and storage amongst the CCR CCGT generating station fleet. This means that the construction cost will be relatively high because of the lack of experience.

  However, within Scenario B, it is assumed that both onshore and offshore transport pipelines are based on new assets that would be sized to SEE, but that the storage infrastructure can be re-used. Storage site re-use will allow for a reduction in storage costs.

- Scenario C: Nth of a Kind Plant, with shared Transport and Storage

  Scenario C assumes that the CCGT unit(s) will be fitted with CO_2 capture equipment, transport and storage after the majority of the CCR CCGT generation station fleet. This means that the construction cost will be relatively lower due to learning curve effects.

  Within Scenario C, it is assumed that a CO_2 network with several other emitters will be used. To recognise this possibility, the economic model has been run for a case where the transport and storage system (and associated costs) is shared[24]. Associated costs allocated to SEE have been assumed to be approximately 16 per cent in this economic assessment.

9.6 Sensitivity Analysis

9.6.1 For each of the economic assessment scenarios, the economic model has the capability to vary the three sensitivities listed below:

- Discount Rate

  Whilst a nominal 10 per cent discount rate is considered to be a reasonable value for a base case analysis for a CCGT generation station project, the retrofitting of CO_2 capture equipment, transport and storage at some time in the future is considered to present an additional risk to developers. Therefore, a higher risk-adjusted discount rate of 12.5 per cent has been added to reflect this risk.

- Gas Price

  Volatility in the gas market (assuming continued linkage with oil) in the UK in recent years has shown that there remains significant uncertainty in the longer term forward gas price. Therefore, the economic assessment has modelled what is considered to be outlying possibilities for the gas price with a ±30 per cent uncertainty range.

- Capital Cost

  The capital cost for the CCGT unit(s) has been stressed with a ±10 per cent uncertainty range. This uncertainty is applied to the CCGT unit(s) and the CO_2 capture equipment, transport and storage.

9.6.2 Based on these three sensitivities, the economic model runs illustrated in this economic assessment show the cumulative effects of factors increasing the cost of electricity (high gas price, high capital cost, high discount rate), and of factors decreasing the cost of electricity (low gas price, low capital cost). Accordingly, Table 9.2 describes the high and low sensitivity runs for each economic assessment scenario.

[24] Whilst the CCR Guidance states that outsourcing transport and storage cannot be assumed in a CCR Feasibility Study, such an option is included for comparative purposes.

TABLE 9.2: SENSITIVITY ANALYSIS RUNS

	Discount Rate	*Gas Price*	*Capital Costs*
High	12.5 %	+30 %	+10 %
Low	10 %	-30 %	-10 %

9.7 Economic Assessment

Scenario 1

9.7.1 The variation of generation costs with carbon price is shown in Insert 9.2 and Insert 9.3. The generation costs (in p/kWh) is shown on the y-axis and the carbon price is shown on the x-axis. Solid lines represent the Base Case for each Scenario and the dotted lines represent the upper and lower limits of the sensitivity analysis runs.

9.7.2 Insert 9.2 compares the results of the economic model for the CCGT units (black line) with Scenario A (blue line) and Scenario B (green line). Insert 9.2 shows that for carbon prices in the range €0/tonne to €200/tonne:

- For the Base Case (i.e. without CO_2 capture equipment, transport and storage), the lifetime cost of electricity ranges between 5.9 p/kWh and 9.6 p/kWh;
- For Scenario A the lifetime cost of electricity ranges between 8.1 p/kWh and 8.5 p/kWh; and,
- For Scenario B, the lifetime cost of electricity ranges between 8.0 p/kWh and 8.4 p/kWh.

9.7.3 Therefore, the break even carbon price such that the cost of electricity for the CCGT unit under Scenario A remains the same value as that for the CCGT unit (without CO_2 capture equipment, transport and storage) is approximately €134/t CO_2. The break even carbon price for the CCGT unit under Scenario B only decreases by a few €/t CO_2.

9.7.4 Insert 9.3 compares the results of the economic model the CCGT unit with Scenario C (red line). Insert 9.3 shows that for carbon prices in the range €0/tonne to €200/tonne:

- For Scenario C, the lifetime cost of electricity ranges between 7.3 p/kWh and 7.8 p/kWh.

9.7.5 Therefore, the break even carbon price such that the cost of electricity for the CCGT unit under Scenario C remains the same value as that for the CCGT unit (without CO_2 capture equipment, transport and storage) is approximately €88/t CO_2.

9.7.6 A comparison of the break even carbon prices for the various Scenarios is shown in Insert 9.4.

Scenario 2

9.7.7 The variation of generation costs with carbon price is shown in Insert 9.5 and Insert 9.6. The generation costs (in p/kWh) is shown on the y-axis and the carbon price is shown on the x-axis. Solid lines represent the Base Case for each Scenario and the dotted lines represent the upper and lower limits of the sensitivity analysis runs.

9.7.8 Insert 9.5 compares the results of the economic model for the CCGT unit (black line) with Scenario A (blue line) and Scenario B (green line). Insert 9.5 shows that for carbon prices in the range €0/tonne to €200/tonne:

- For the Base Case (i.e. without CO_2 capture equipment, transport and storage), the lifetime cost of electricity ranges between 5.7 p/kWh and 9.3 p/kWh;
- For Scenario A the lifetime cost of electricity ranges between 8.3 p/kWh and 8.8 p/kWh; and,
- For Scenario B, the lifetime cost of electricity ranges between 8.2 p/kWh and 8.7 p/kWh.

9.7.9 Therefore, the break even carbon price such that the cost of electricity for the CCGT unit under Scenario A remains the same value as that for the CCGT unit (without CO_2 capture equipment, transport and storage) is approximately €166/t CO_2. The break even carbon price for the CCGT unit under Scenario B only decreases by a few €/t CO_2.

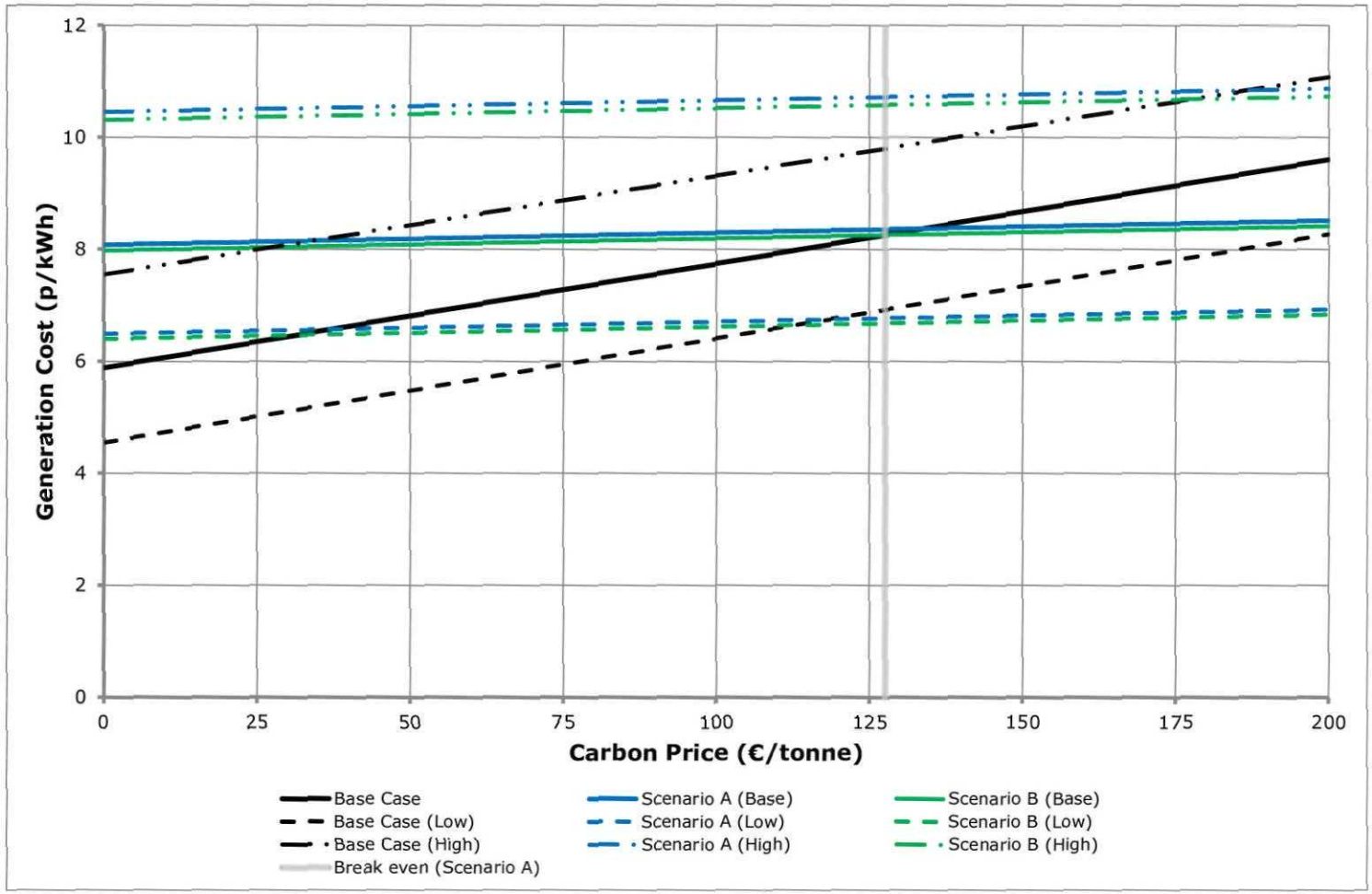
9.7.10 Insert 9.6 compares the results of the economic model for the CCGT unit with Scenario C (red line). Insert 9.3 shows that for carbon prices in the range €0/tonne to €200/tonne:

- For Scenario C, the lifetime cost of electricity ranges between 7.6 p/kWh and 8.0 p/kWh.

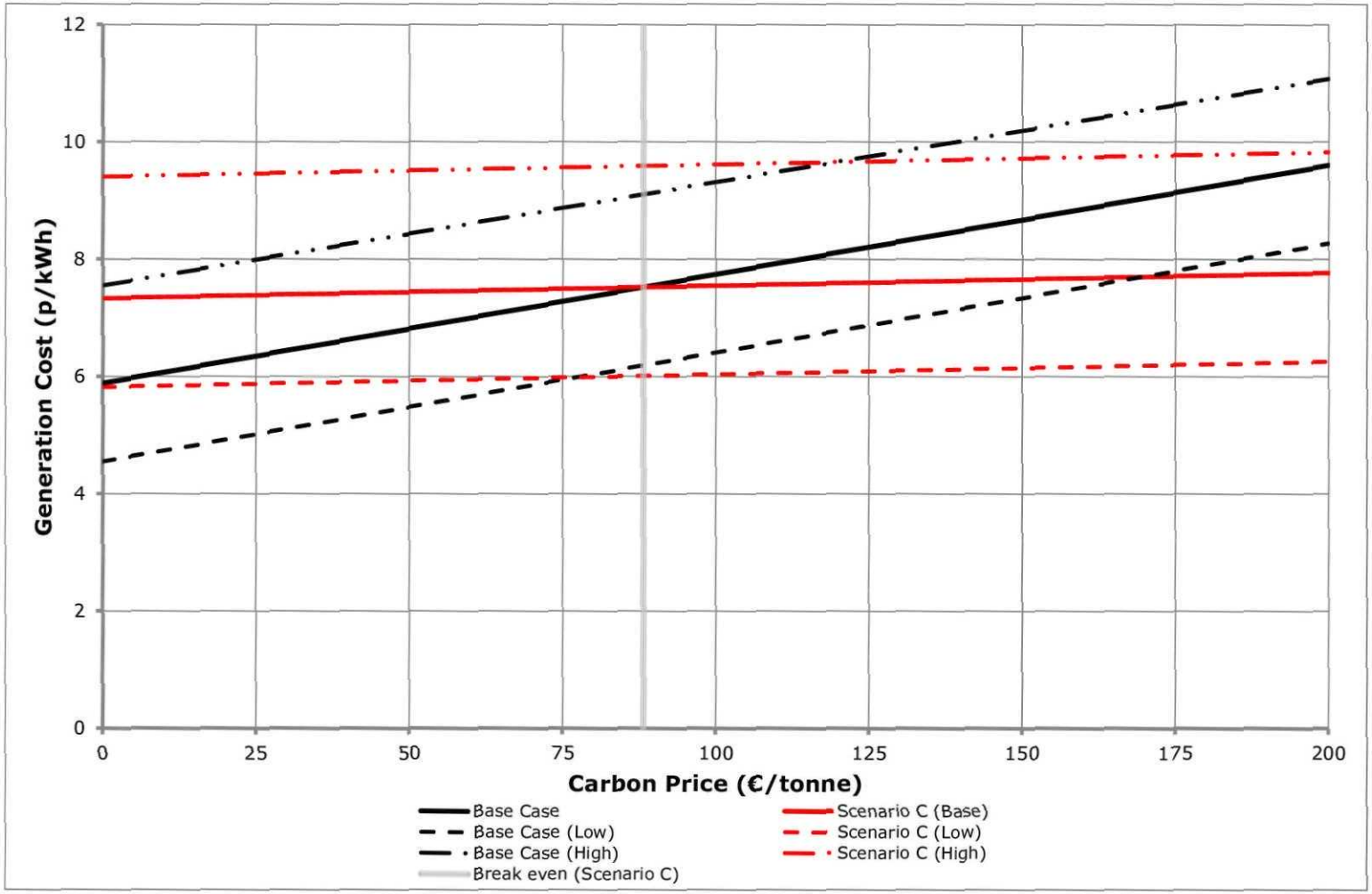
9.7.11 Therefore, the break even carbon price such that the cost of electricity for the CCGT unit under Scenario C remains the same value as that for the CCGT unit (without CO_2 capture equipment, transport and storage) is approximately €118/t CO_2.

9.7.12 A comparison of the break even carbon prices for the various Scenarios is shown in Insert 9.7.

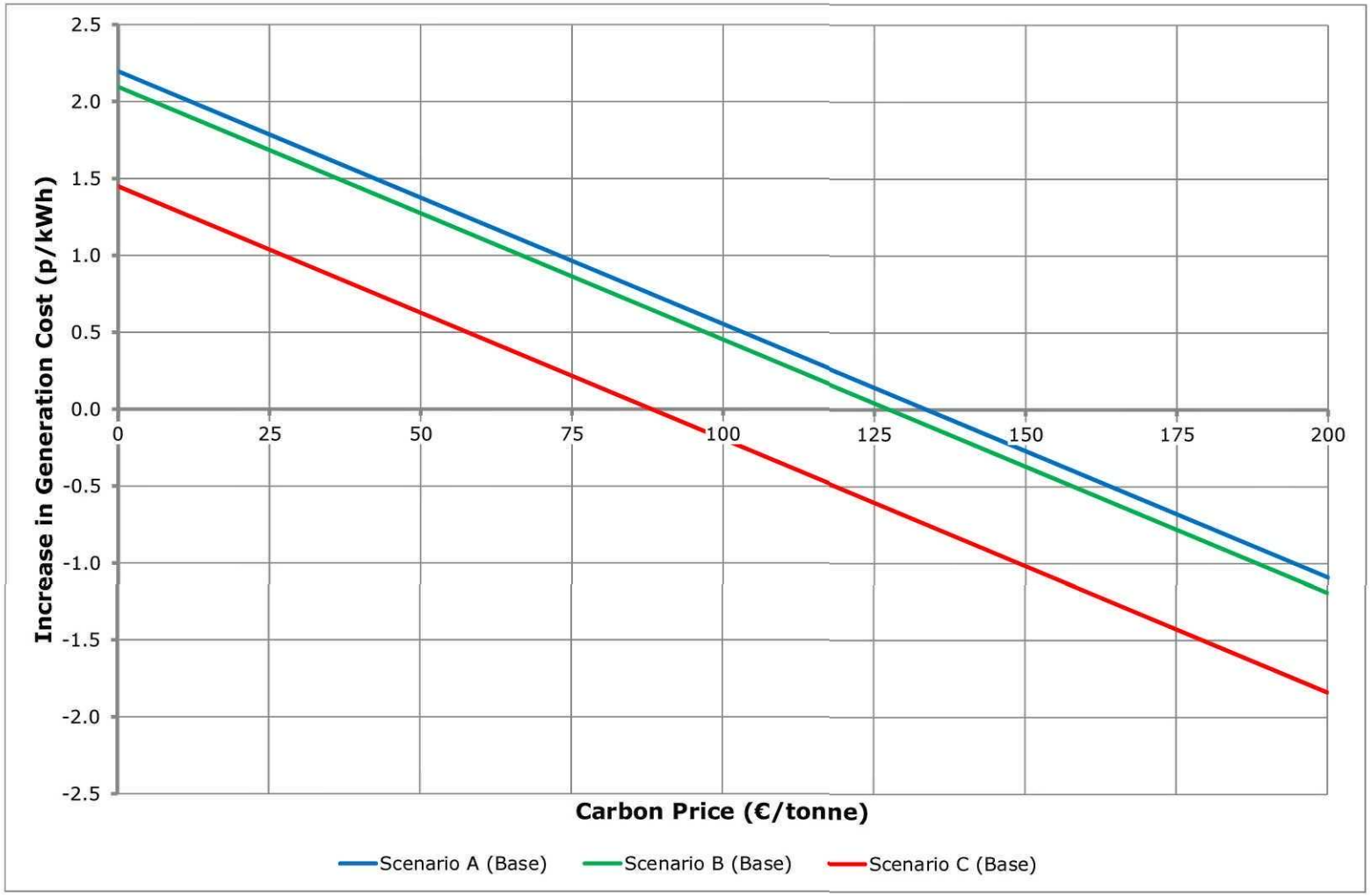
INSERT 9.2: SCENARIO 1 - ECONOMIC MODEL FOR THE CCGT UNIT (BASE CASE) COMPARED WITH SCENARIO A AND SCENARIO B



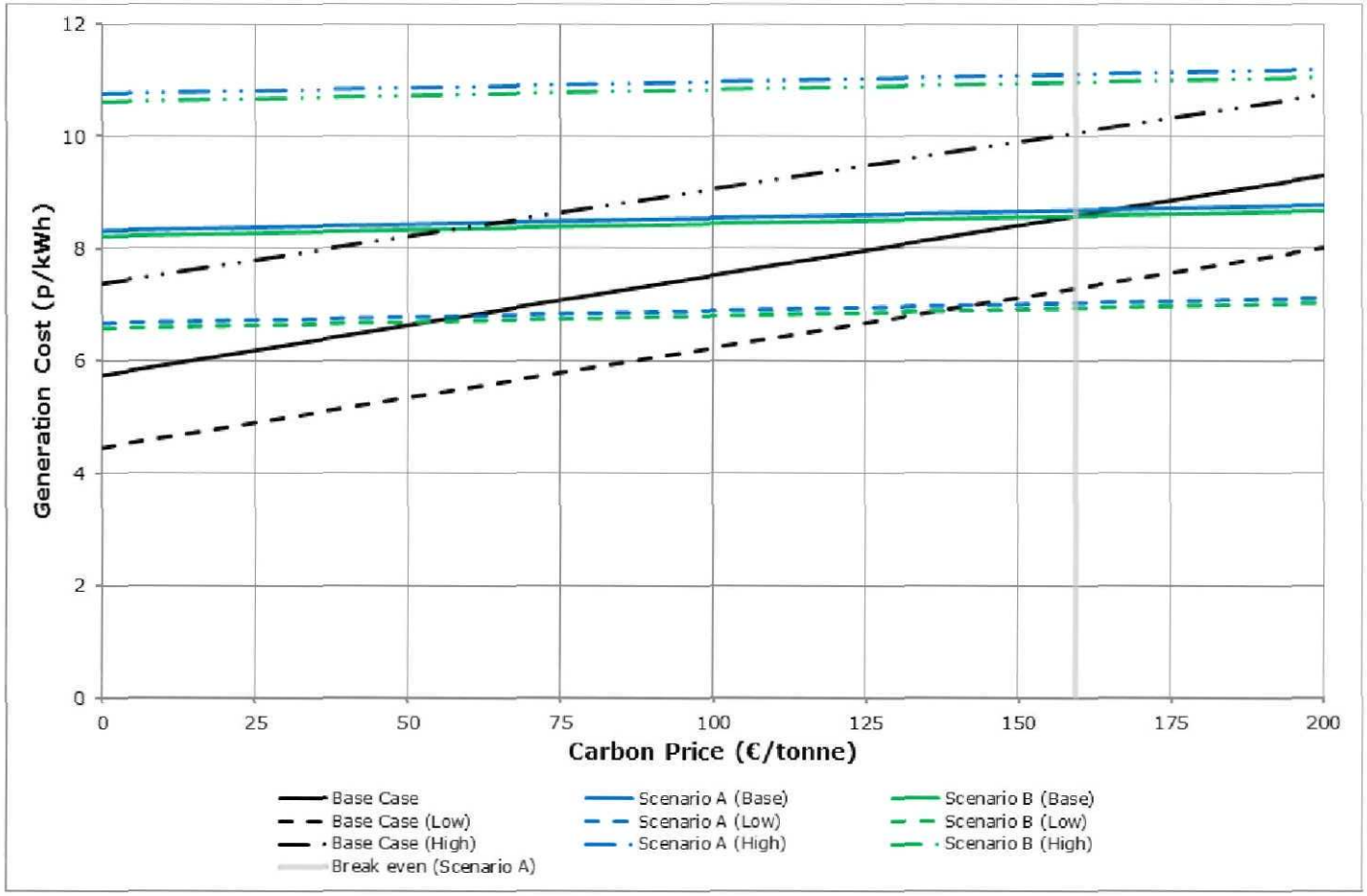
INSERT 9.3: SCENARIO 1 - ECONOMIC MODEL FOR THE CCGT UNIT (BASE CASE) COMPARED WITH SCENARIO C



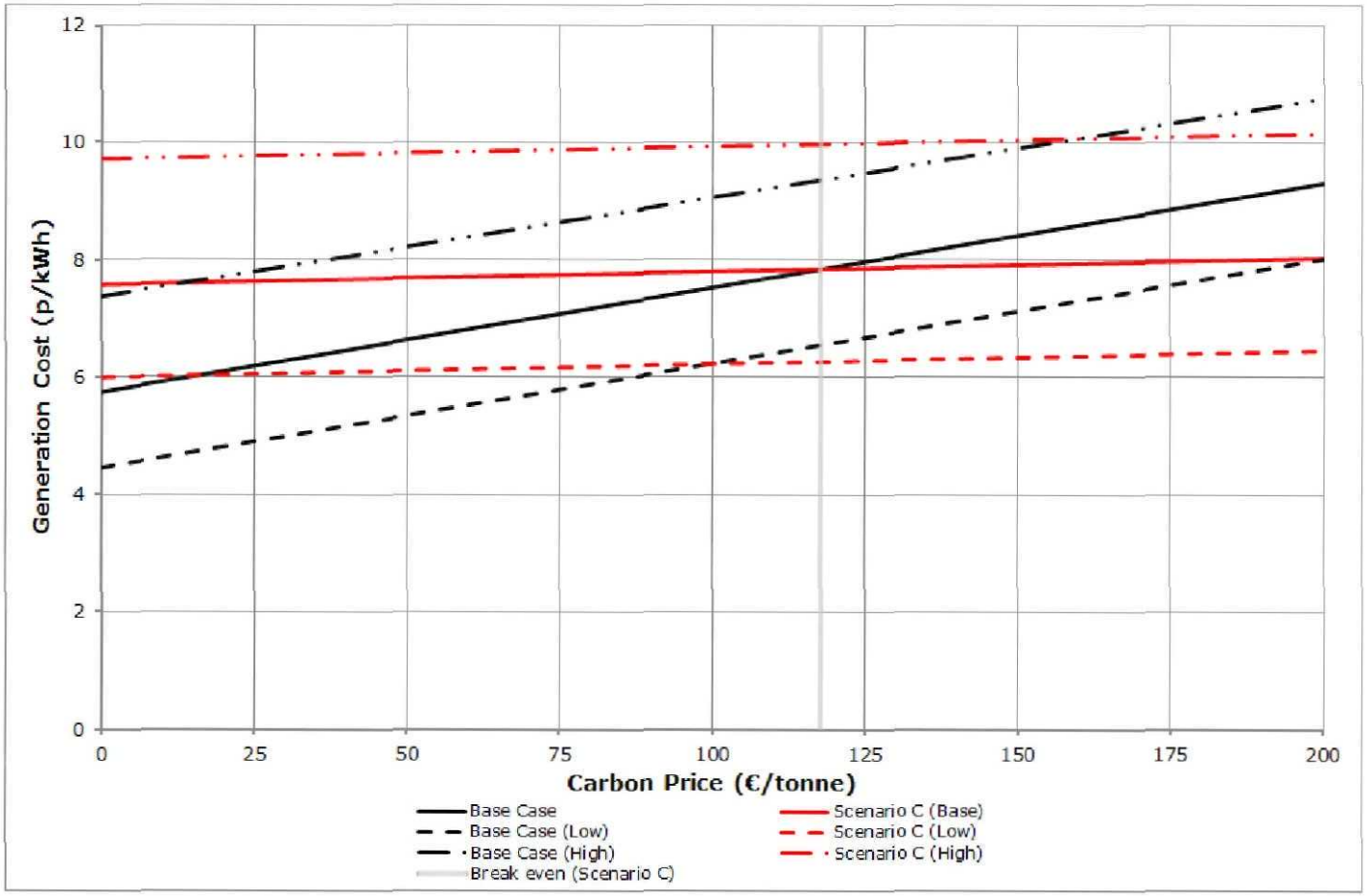
INSERT 9.4: SCENARIO 1 - COMPARISON OF THE BREAK EVEN CARBON PRICES



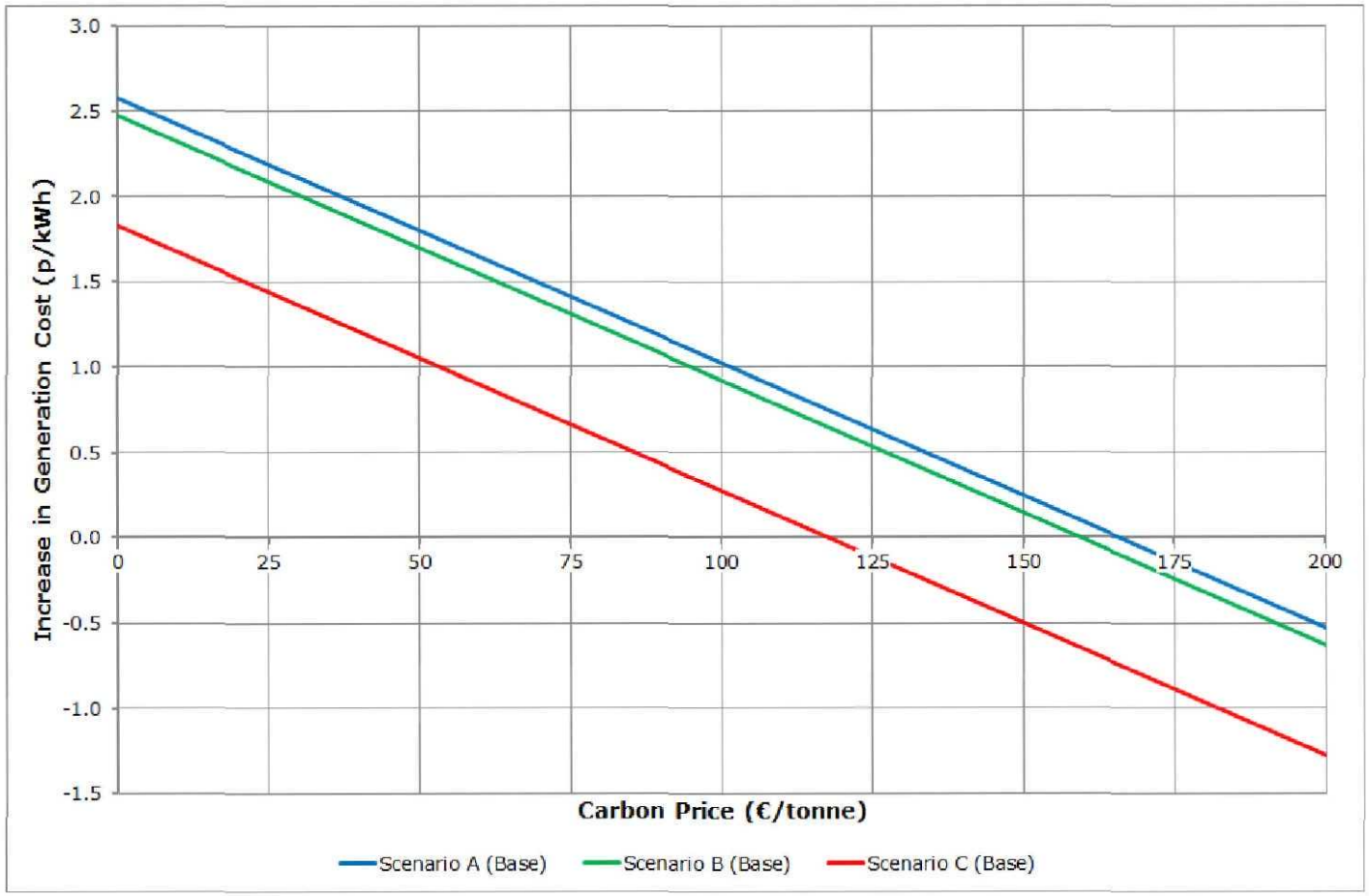
INSERT 9.5: SCENARIO 2 - ECONOMIC MODEL FOR THE CCGT UNIT (BASE CASE) COMPARED WITH SCENARIO A AND SCENARIO B



INSERT 9.6: SCENARIO 2 - ECONOMIC MODEL FOR THE CCGT UNIT (BASE CASE) COMPARED WITH SCENARIO C



INSERT 9.7: SCENARIO 2 - COMPARISON OF THE BREAK EVEN CARBON PRICES



9.8 Impact of Capacity Factor

9.8.1 The assumed capacity factor of 75% for the CCGT unit has an impact on the cost of electricity.

Scenario 1

9.8.2 If the capacity factor is adjusted to 100%, then in the economic model for the CCGT unit, the lifetime cost of electricity ranges between 5.5 p/kWh (at €0/t CO_2) and 9.2 p/kWh (at €200/t CO_2).

9.8.3 In addition, if the capacity factor is adjusted to 100%:

- Under Scenario A, the break even carbon price such that the cost of electricity for the CCGT unit under Scenario A remains the same as that for the CCGT unit (without CO_2 capture equipment, transport and storage) would drop to approximately €109/t CO_2; and,
- Under Scenario C, the break even carbon price such that the cost of electricity for the CCGT unit under Scenario C remains the same as that for the CCGT unit (without CO_2 capture equipment, transport and storage) would drop to approximately €75/t CO_2.

Scenario 2

9.8.4 If the capacity factor is adjusted to 100%, then in the economic model for the CCGT unit, the lifetime cost of electricity ranges between 5.3 p/kWh (at €0/t CO_2) and 8.9 p/kWh (at €200/t CO_2).

9.8.5 In addition, if the capacity factor is adjusted to 100%:

- Under Scenario A, the break even carbon price such that the cost of electricity for the CCGT unit under Scenario A remains the same as that for the CCGT unit (without CO_2 capture equipment, transport and storage) would drop to approximately €139/t CO_2; and,
- Under Scenario C, the break even carbon price such that the cost of electricity for the CCGT unit under Scenario C remains the same as that for the CCGT unit (without CO_2 capture equipment, transport and storage) would drop to approximately €103/t CO_2.

9.9 Conclusions

Scenario 1

9.9.1 The results of the economic assessment indicate that the retrofitting of CO_2 capture equipment, transport and storage to the CCGT unit becomes economic:

- Under Scenario A (First of a Kind Plant, with dedicated Transport and Storage) on the basis of carbon prices of approximately €134/t CO_2; and,
- Under Scenario C (Nth of a Kind Plant, with shared Transport and Storage) on the basis of carbon prices of approximately €88/t CO_2.

9.9.2 Increasing the assumed capacity factor from 75% to 100%, the results of the economic assessment indicate that the retrofitting of CO_2 capture equipment, transport and storage to the CCGT unit becomes economic:

- Under Scenario A (First of a Kind Plant, with dedicated Transport and Storage) on the basis of carbon prices of approximately €109/t CO_2; and,
- Under Scenario C (Nth of a Kind Plant, with shared Transport and Storage) on the basis of carbon prices of approximately €75/t CO_2.

Scenario 2

9.9.3 The results of the economic assessment indicate that the retrofitting of CO_2 capture equipment, transport and storage to the CCGT unit becomes economic:

- Under Scenario A (First of a Kind Plant, with dedicated Transport and Storage) on the basis of carbon prices of approximately €166/t CO_2; and,
- Under Scenario C (Nth of a Kind Plant, with shared Transport and Storage) on the basis of carbon prices of approximately €118/t CO_2.

9.9.4 Increasing the assumed capacity factor from 75% to 100%, the results of the economic assessment indicate that the retrofitting of CO_2 capture equipment, transport and storage to the CCGT unit becomes economic:

- Under Scenario A (First of a Kind Plant, with dedicated Transport and Storage) on the basis of carbon prices of approximately €139/t CO_2; and,
- Under Scenario C (Nth of a Kind Plant, with shared Transport and Storage) on the basis of carbon prices of approximately €103/t CO_2.

9.9.5 However, it should be noted that (at the time of writing) there is currently a pattern of an increasing supply of allowances and international credits, coupled with low demand. In addition, whilst the carbon price is the result of a wide range of factors, the recent economic recession has had (and continues to have) a major impact. Indeed, in mid-2014 the EU ETS carbon price was down at around €5/t CO_2.

10 REQUIREMENT FOR HAZARDOUS SUBSTANCES CONSENT

10.1 CCR Guidance Requirement

10.1.1 The CCR Guidance states (at paragraph 70) that: *"Operational CCS is likely to bring onto combustion plant sites chemicals and gases which are not currently present (or not present in such quantities) on such sites. Depending on the hazard classification of these substances and the quantity present, sites with operational CCS could become subject to the Council Directive 96/82/EC, as amended by Directive 2003/105/EC, known as the Seveso II Directive. The aim of the Directive is to prevent major accidents which involved dangerous substances and limit their consequences for man and the environment. One particular requirement of the Directive is that Member States must ensure that these objectives are taken into account in their land use planning policies. The Directive is implemented in the UK by the Planning (Hazardous Substances) Act 1990 and Regulations made under the Act which include the Planning (Hazardous Substances) Regulations 1992"*.

10.1.2 Furthermore, the CCR Guidance states (at paragraph 71) that: *"One of the consequences of operating a site at which hazardous substances (currently classified as such under the Planning (Hazardous Substances) Regulations 1992) are present is the need to obtain* [Hazardous Substances Consent] *HSC".*

10.1.3 Therefore, if an applicant's proposals for the CO_2 capture plant technology and CO_2 transport involve the storage or use on site of substances currently classified under Schedule 1 of the Regulations, it may be necessary to apply for HSC at the same time as applying for initial Consent.

10.1.4 Therefore, the CCR Guidance requirements are to determine the need, or otherwise, to apply for a HSC.

10.2 Evaluation of the Requirement for Hazardous Substance Consent

10.2.1 This Section evaluates the requirement for a HSC for both Scenario 1 and Scenario 2.

10.2.2 The presence of certain hazardous substances on, under or above land at or above set threshold quantities (Controlled Quantities) may require a HSC under the Planning (Hazardous Substances) Act 1990 (as amended). The threshold quantities are set out in the Planning (Hazardous Substances) Regulations 1992 (as amended).

10.2.3 In addition to the requirement for a HSC, the presence of certain hazardous substances on, under or above land at or above the set threshold quantities may require the preparation of emergency plans under the Control of Major Accident Hazards Regulations 1999 (as amended).

10.2.4 Accordingly, this Section evaluates the potential requirement for a HSC and emergency plans based on:

- The chemicals / substances involved in the CCGT unit;
- The chemicals / substances involved in the post-combustion CO_2 capture plant technology (using amine solvents); and,
- The captured CO_2.

Chemicals / Substances involved in the CCGT Unit

Application of the Planning (Hazardous Substances) Regulations 1992

10.2.5 Operation of the CCGT unit will require the use of natural gas as a fuel. The Planning (Hazardous Substances) Regulations 1992 (as amended) provides that the Controlled Quantity of natural gas is 15 tonnes. Natural gas will be delivered via a dedicated gas pipeline, and no natural gas will be stored on-site. As such, a HSC is not likely required on the basis of the chemicals / substances involved in the CCGT unit.

Application of the Control of Major Accident Hazards Regulations 1999 (As Amended) to the Pipelines On-Site

10.2.6 The dedicated gas pipeline on-site does not fall inside the scope of the Control of Major Accident Hazards Regulations 1999 (as amended). As such, emergency plans are not likely required on the basis of the chemicals / substances involved in the CCGT unit.

Chemicals / Substances involved in the Post-Combustion CO_2 Capture Plant Technology (using Amine Solvents)

10.2.7 As noted in Section 5 of the Original CCR Feasibility Study and Section 4 of this Revised CCR Feasibility Study, the feasibility of CCR for the CCGT unit has been assessed on the basis of the best currently available technology which, for CO_2 capture from flue gases (post-combustion CO_2 capture), is chemical absorption using amine solvents.

10.2.8 The most likely amine solvent is MEA, which would not normally be presented on the SEE site. The MEA that would be present on the SEE site would either be stored as a pure substance, or be used in the CO_2 capture process as a solution. These are referred to as MEA substance and MEA preparation respectively.

10.2.9 In terms of MEA substance, the current classifications are XN R20/21/22 and C R34. These classifications translate as 'harmful' and 'corrosive'. In terms of MEA preparation, a solution of ≥ 25 per cent would have the same classifications as MEA substance.

10.2.10 Accordingly, in terms of both MEA substance and MEA preparation, the current classifications ('harmful' and 'corrosive') are such that a HSC is not required. In addition, discussions with DECC's Carbon Capture Readiness Team on the risks associated with MEA have confirmed that, at present, the HSE does not consider MEA to be subject to any requirement for a HSC or be subject to any on-site storage limits.

Captured CO_2

10.2.11 As noted in the CCR Guidance, it may be that (during operation with CO_2 capture, compression, transportation and storage) dense phase CO_2 would be present on-site and within the CO_2 pipeline once the CO_2 is compressed in preparation for transport. Whilst dense phase CO_2 is not currently classified as hazardous, it is now recognised that an accidental release of large quantities of dense phase CO_2 could result in a major accident. As such, there is currently extensive on-going research into the hazard potential of dense phase CO_2. The results of this on-going research will inform future decisions on dense phase CO_2 and whether a classification review (i.e. dense phase CO_2 is classified as hazardous) is necessary.

Application of the Planning (Hazardous Substances) Regulations 1992

10.2.12 In terms of the CO_2 capture and compression plant / equipment, it is anticipated that no CO_2 (gaseous or dense phase) will be stored on-site. As such, a HSC is not likely required on the basis of the captured CO_2 in the CO_2 capture and compression plant / equipment.

10.2.13 In terms of CO_2 transport, CO_2 (gaseous and / or dense phase) will be present in CO_2 pipelines on-site. Subject to the classification review, the CO_2 pipelines on-site may fall inside the scope of the Planning (Hazardous Substance) Regulations 1992 (as amended). However, until the classification is known and the information on the Controlled Quantity is available, it is not known whether the Planning (Hazardous Substances) Regulations 1992 (as amended) would apply. In this regard, SEEL will hold informal discussions with South Holland District Council (the local planning authority) about the potential issues surrounding dense phase CO_2, including the implications behind the possible presence of small amounts on site. These informal discussions will continue until further information concerning the classification of dense phase CO_2 is available. This will ensure that there is early identification of any potential implications on South Holland District Council's long term plan for the area. However, at this stage it is felt that no formal discussions or preparations are necessary.

Application of the Control of Major Accident Hazards Regulations 1999 (As Amended) to the Pipelines On-Site

10.2.14 In terms of the CO_2 capture and compression plant / equipment, it is anticipated that no CO_2 (gaseous or dense phase) will be stored on-site. As such, emergency plans are not likely required on the basis of the CO_2 capture and compression plant / equipment.

10.2.15 In terms of CO_2 transport, the CO_2 pipelines on-site do not fall inside the scope of the Control of Major Accident Hazards Regulations 1999 (as amended). As such, emergency plans are not likely required on the basis of the CO_2 pipelines on-site.

Conclusion on the Potential Requirement for HSC

10.2.16 On the basis of the proposed CO_2 capture plant technology and the current classifications of the chemicals / substances which are likely to be on site, it is concluded that a HSC is not required at this stage.

10.2.17 If a HSC is required at the point of retrofitting and integration of CO_2 capture plant technology, an application would be made at that stage. This is because any detailed information which would be required for the application will not be known until that stage.

Conclusion on the Potential Requirement for Emergency Plans

10.2.18 On the basis of the proposed CO_2 capture plant technology and the current classifications of the chemicals / substances which are likely to be on site, it is concluded that emergency plans are not required at this stage.

10.2.19 If emergency plans are required at the point of retrofitting and integration of CO_2 capture plant technology, these would be prepared at that stage. This is because any detailed information which would be required will not be known until that stage.

10.3 Future Considerations

10.3.1 The requirement for a HSC will be reviewed as part of the Status Reports. These Status Reports will provide an opportunity for reassessment / review of the above, particularly regarding developments / changes in classifications / CO_2 capture technologies.

11 CONCLUSIONS

11.1.1 SEEL is submitting an application to the Secretary of State for the Original Consent to be varied (the Variation Application). If the Original Consent is varied as per the Variation Application, SEE will provide up to 945 MW of power generation capacity. In providing up to 945 MW of power generation capacity, the Proposed Development will either comprise:

- Scenario 1: Up to 945 MW of CCGT units; or,
- Scenario 2: Up to 645 MW of CCGT units and less than 300 MW of Open Cycle Gas Turbine (OCGT) units.

11.1.2 In addition, if the Original Consent is varied as per the Variation Application, the commencement of the deadline for the Consent will be 5 years from the date of granting the variation. Similarly, the commencement deadline for the deemed planning permission will be 5 years from the date of granting the variation.

11.1.3 To accompany the Variation Application, SEEL is providing the following information to DECC:

- An ES FID (the Variation Application ES FID), which includes (amongst other items):
  - The rationale for proposing that the Original Consent is varied;
  - An assessment of whether the likely significant effects on the environment of the Proposed Development differ from those described in the March 2009 ES; and,
    - Where there is potential for the likely significant effects to differ, an updated impact assessment;
    - Where there is no potential for the likely significant effects to differ, an explanation and / or supporting information.
- A Revised CHP Assessment;
- A Revised CCR Feasibility Study; and,
- A Supplementary Flood Risk Assessment.

11.1.4 This Document is the Revised CCR Feasibility Study which accompanies the Variation Application.

11.1.5 For both Scenario 1 and Scenario 2, this Revised CCR Feasibility Study has demonstrated that the Proposed Development will remain fully compliant with the requirements of the EU CCS Directive (and the EU IED Directive), the CCR Regulations and the CCR Guidance. Accordingly, this Revised CCR Feasibility Study demonstrates that it remains feasible to retrofit CO_2 capture, transport and storage to the CCGT unit(s) within their 35 year operating lifetime.

FIGURES



Notes

1. DO NOT SCALE FROM THIS DRAWING.
2. FOR KEY TO DRAWINGS/GRAPHICAL SYMBOLS SEE LEGEND.
3. THIS IS NOT AN INSTALLATION DRAWING, NOR A COORDINATION DRAWING.

LEGEND:

1. HEAT RECOVERY STEAM GENERATOR
2. STEAM TURBINE AREA
3. GAS TURBINE AREA
4. CO2 LOW PRESSURE STATION
5. GAS TURBINE INLET FILTER
6. DEMINERALIZED WATER STORAGE TANK
7.
8. GAS TURBINE GENERATOR TRANSFORMERS
9. SWITCHYARD
10. AIR COOLED CONDENSER
11. WAREHOUSE/MAINTENANCE/ADMIN/CONTROL
12.
13.
14. STEAM TURBINE GENERATOR TRANSFORMER
15. AUXILIARY BOILER
16. GAS CONDITIONING
17. REFUSE COLLECTION/STORAGE
18. FIN FAN COOLERS
19. SUDS POND
20. ELECTRICAL ANNEX
21. WATER TREATMENT PLANT
22. FUTURE SCR AMMONIA SKID
23. FUTURE AMMONIA STORE AND BUND
24. STACK
25. GAS/GAS HEAT EXCHANGER
26. BLOWER
27. DIRECT CONTACT COOLER
28. ABSORBER
29. STRIPPER
30. RECLAIMER
31. SOLVENT STORAGE TANK
32. CO2 COMPRESSOR
33. FIN FAN COOLERS
34. CO2 BATTERY LIMIT
35. CW PUMP HOUSE

Rev	Description	Date	By	Chk	App
P01	FOR INFORMATION	09/03/15	SL	EA	

INTERGEN/SPALDING ENERGY EXPANSION LIMITED

SPALDING ENERGY EXPANSION

RAMBOLL
tel 020 7462 5281 fax 020 7323 4645 london@ramboll.co.uk
www.ramboll.co.uk

FIGURE 1A PROPOSED LAYOUT SCENARIO 1 CCGT AND CCS

Scale:	Date:	Drawn:	Checked:
NTS	MAR 2015	SL	

Drawing No.:	Rev:
482302-11-01	P01



Notes

1. THIS DRAWING IS TO BE READ IN CONJUNCTION WITH ALL OTHER RELEVANT DRAWINGS AND SPECIFICATIONS.
2. DO NOT SCALE FROM THIS DRAWING.
3. FOR KEY TO DRAWINGS/GRAPHICAL SYMBOLS SEE LEGEND.
4. THIS IS NOT AN INSTALLATION DRAWING, NOR A COORDINATION DRAWING.

LEGEND:

1. HEAT RECOVERY STEAM GENERATOR
2. TURBINE HALL
3. GAS FINAL FILTER AND PREHEATING
4. GT INLET FILTER
5. DEMINERALIZED WATER TANK
6. RAW WATER STORAGE TANK
7. FIRE FIGHTING PUMPS
8. WATER TREATMENT PLANT
9. GENERATOR TRANSFORMER
10. SWITCHYARD
11. GAS PRESSURE REDUCTION STATION
12. AIR COOLED CONDENSER
13. AUXILIARY BOILER
14. WORKSHOP/WAREHOUSE
15. POWER CONTROL CENTRES
16. RAIN WATER RETENTION
17. GAS/GAS HEAT EXCHANGER
18. BLOWER
19. DIRECT CONTACT COOLER
20. ABSORBER
21. STRIPPER
22. RECLAIMER
23. SOLVENT STORAGE TANK
24. CO2 COMPRESSOR
25. FIN FAN COOLERS
26. CO2 BATTERY LIMIT
27. CW PUMP HOUSE
28. OPEN CYCLE GAS TURBINES

Rev	Description	Date	By	Chk	App
P02	NUMBERING, TITLE CHANGED	10/03/15	SL	EA	
P01	FOR INFORMATION	16/02/15	SL	EA	

INTERGEN/SPALDING ENERGY EXPANSION LIMITED

SPALDING ENERGY EXPANSION

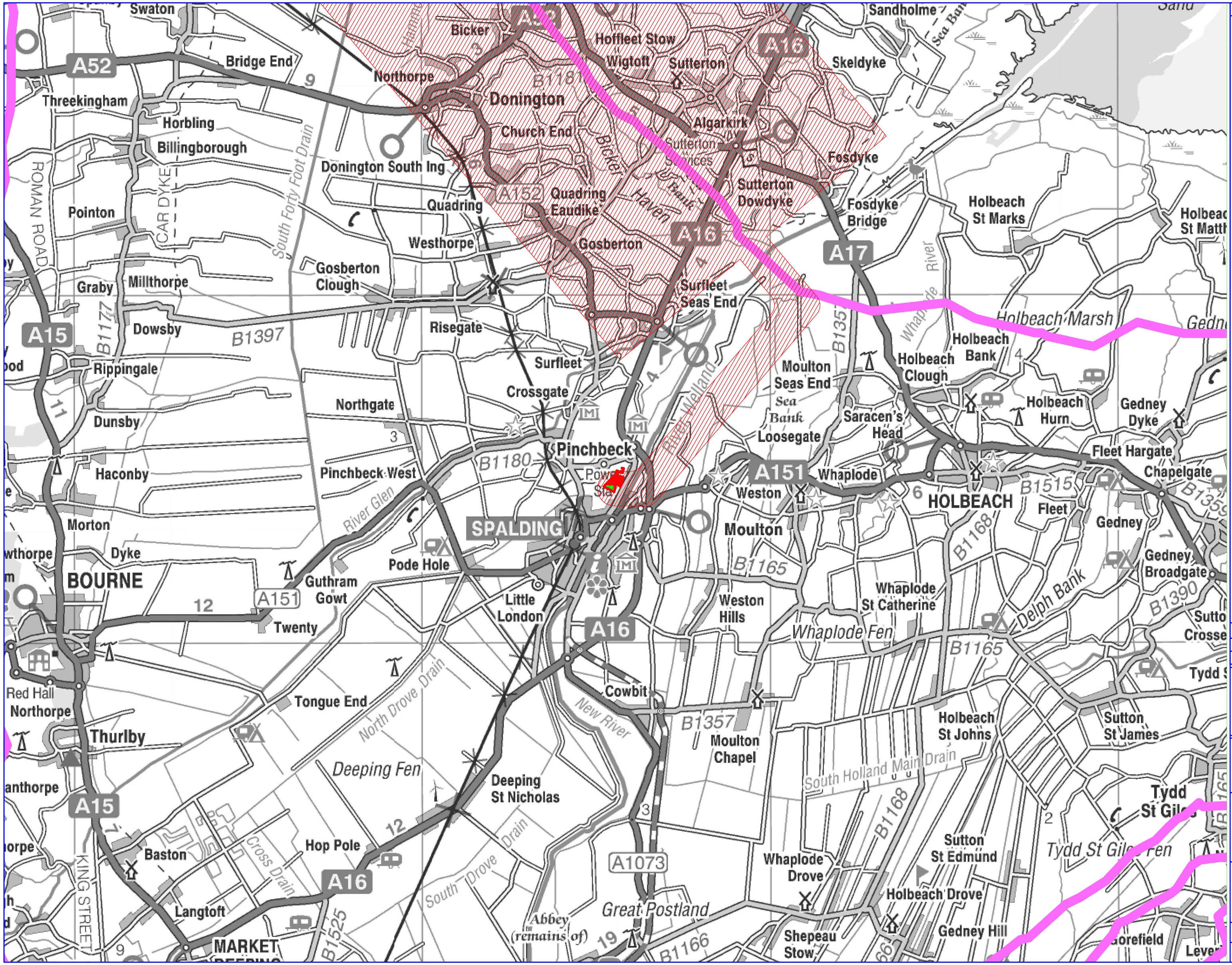
RAMBOLL
tel 020 7462 5281 fax 020 7323 4645 london@ramboll.co.uk
www.ramboll.co.uk

FIGURE 1B PROPOSED LAYOUT SCENARIO 2 CCGT, OCGT AND CCS

Scale:	Date:	Drawn:	Checked:
NTS	MAR 2015	SL	EA

Drawing No.: 482302-1-01

Rev: P02



Notes

1. THIS DRAWING IS TO BE READ IN CONJUNCTION WITH ALL OTHER RELEVANT DRAWINGS AND SPECIFICATIONS.
2. DO NOT SCALE FROM THIS DRAWING.
3. THIS IS NOT AN INSTALLATION DRAWING, NOR A COORDINATION DRAWING.

Rev	Description	Date	By	Chk	App
P01	FOR INFORMATION	16/02/15	SL	EA	

INTERGEN/SPALDING ENERGY EXPANSION LIMITED

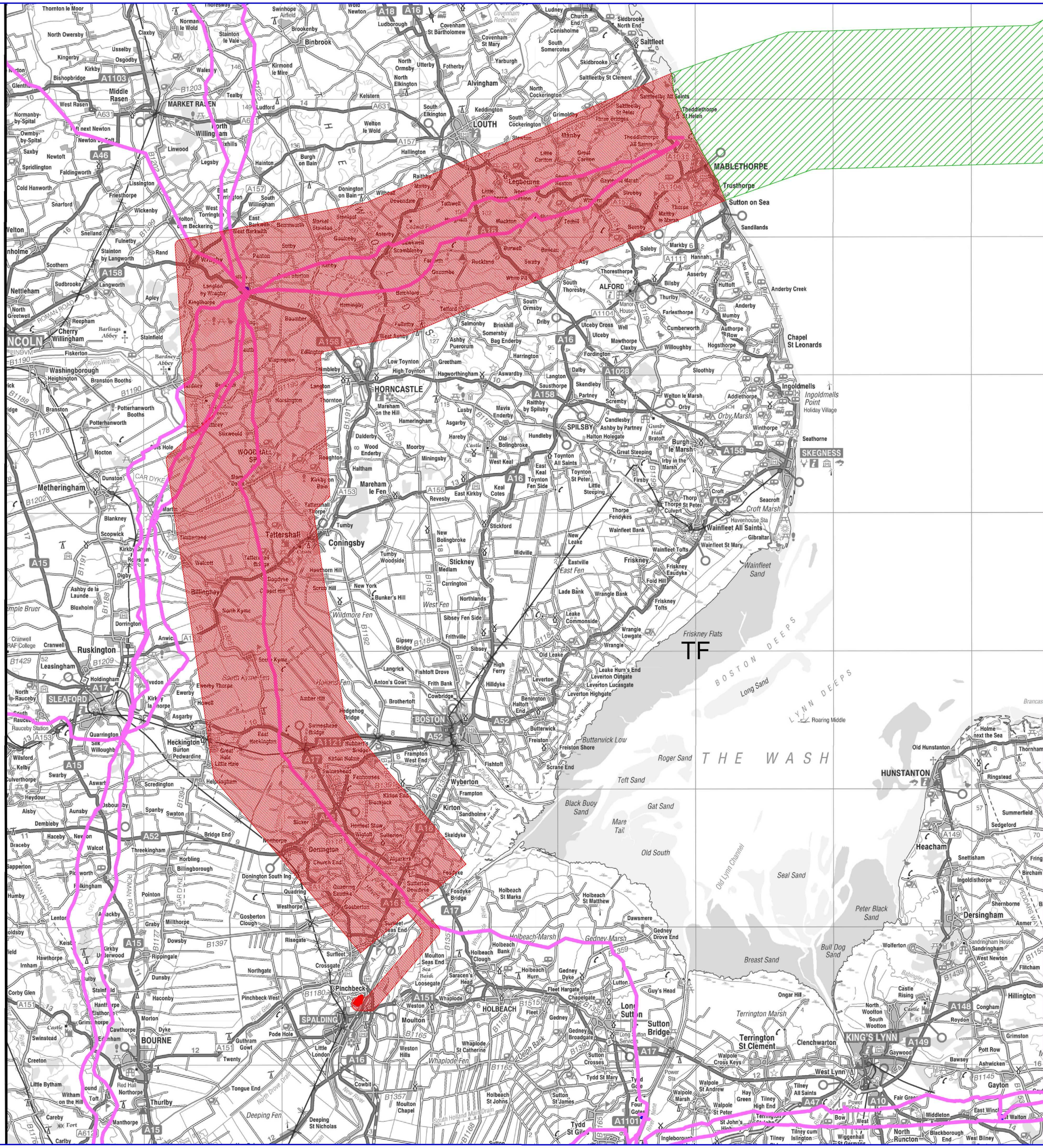
SPALDING ENERGY EXPANSION

RAMBOLL
tel 020 7462 5281 fax 020 7323 4645 london@ramboll.co.uk
www.ramboll.co.uk

FIGURE 2A ON SHORE CO2 PIPELINE INDICATIVE ROUTE (FIRST 10KM)

Scale:	Date:	Drawn:	Checked:
1:50000 @ A1	FEB 2015	SL	

Drawing No.: 482302-3-01 Rev: P01



Notes

1. THIS DRAWING IS TO BE READ IN CONJUNCTION WITH ALL OTHER RELEVANT DRAWINGS AND SPECIFICATIONS.
2. DO NOT SCALE FROM THIS DRAWING.
3. THIS IS NOT AN INSTALLATION DRAWING, NOR A COORDINATION DRAWING.

Rev	Description	Date	By	Chk	App
P01	FOR INFORMATION	16/02/15	SL	EA	

INTERGEN/SPALDING ENERGY EXPANSION LIMITED

SPALDING ENERGY EXPANSION

RAMBOLL

tel 020 7462 5281 fax 020 7323 4645 london@ramboll.co.uk www.ramboll.co.uk

FIGURE 2B
ON SHORE CO2 PIPELINE INDICATIVE ROUTE

Scale: 1:200000 @ A1 | Date: FEB 2015 | Drawn: SL | Checked:

Drawing No.: 482302-3-02 | Rev: P01



Notes

1. THIS DRAWING IS TO BE READ IN CONJUNCTION WITH ALL OTHER RELEVANT DRAWINGS AND SPECIFICATIONS.
2. DO NOT SCALE FROM THIS DRAWING.
3. THIS IS NOT AN INSTALLATION DRAWING, NOR A COORDINATION DRAWING.

Rev	Description	Date	By Chk	App
P01	FOR INFORMATION	16/02/15	SL EA	

INTERGEN/SPALDING ENERGY EXPANSION LIMITED

SPALDING ENERGY EXPANSION

RAMBOLL
tel 020 7462 5281 fax 020 7323 4645 london@ramboll.co.uk
www.ramboll.co.uk

FIGURE 3
OFF SHORE CO2 PIPELINE INDICATIVE ROUTE

Scale:	Date:	Drawn:	Checked:
1:200000 @ A1	FEB 2015	SL	

Drawing No.: 482302-4-01 Rev: P01

APPENDICES

APPENDIX A: ANNEX C ('ENVIRONMENT AGENCY VERIFICATION OF CCS READINESS NEW NATURAL GAS COMBINED CYCLE POWER STATION USING POST COMBUSTION SOLVENT SCRUBBING') OF THE CCR GUIDANCE

Annex C

Environment Agency verification of CCS Readiness New Natural Gas Combined Cycle Power Station Using Post-Combustion Solvent Scrubbing

Capture Ready Features

Relevant text from IEA GHG Technical Report 2007/4 "CO_2 Capture Ready Plants" is used as a basis for the requirements in this list. See also IEA GHG report 2005/1 'Retrofit of CO_2 Capture to Natural Gas Combined Cycle Power Plants'.

Notes on evidence expected to be provided are shown in bold normal font. Where it is not possible or not considered necessary to provide the evidence this should be justified.

Post-combustion (amine scrubbing)

C1 Design, Planning Permissions and Approvals

Note C1: A pre-feasibility-level conceptual capture retrofit study should be supplied for assessment, showing how the proposed CCR features would make adding post-combustion capture technically feasible, together with an outline level plot plan for the plant retrofitted with capture.

C2 Power Plant Location

Note C2a: The work undertaken on CO_2 transport and storage should be referenced; the exit point of gases from the curtilage of the plant and how this affects the configuration of the capture equipment is the important aspect for the Environment Agency.

Note C2b: Health and Safety items in this section are outside the Environment Agency remit.

C3 Space Requirements

Space will be required for the following:

a) *CO_2 capture equipment, including any flue gas pretreatment and CO_2 drying and compression.*
b) *Space for routing flue gas duct to the CO_2 capture equipment.*
c) *Steam turbine island additions and modifications (e.g. space in steam turbine building for routing large low pressure steam pipe to amine scrubber unit).*
d) *Extension and addition of balance of plant systems to cater for the additional requirements of the capture equipment.*
e) *Additional vehicle movement (amine transport etc).*

f) *Space allocation for storage and handling of amines and handling of CO_2 including space for infrastructure to transport CO_2 to the plant boundary.*

Note C3: It is expected that all of the provisions in a-f above will be implemented, including the provision of space and access to carry out the necessary works at the time of retrofitting without excessive interruptions to normal plant operation. A statement describing how the space allocations were determined and how they will be met is required. Further details are requested in the following sections as appropriate. The space for capture equipment might be significantly reduced if flue gas recycling through the gas turbine is used to concentrate the CO_2, but to validate this option suitable demonstrations of its feasibility by the gas turbine supplier would be required.

C4 Gas Turbine Operation with Increased Exhaust Pressure

The gas turbine (and upstream ducting and heat recovery steam generator, HRSG) must be able to operate with the increased back pressure imposed by the capture equipment, or alternatively space must be provided for a booster fan.

Note C4: A statement is required giving the expected pressure drop required for current commercial capture equipment together with a manufacturer's confirmation that the gas turbine can accommodate this and any effects on the performance, or alternatively describing booster fan specification together with space and other installation requirements.

C5 Flue Gas System

Space should be available for installing new duct work to enable interconnection of the existing flue gas system with the amine scrubbing plant and provisions in the duct work for tie-ins and addition of items such as bypass dampers and isolation dampers will be required as a minimum. If selective catalytic reduction (SCR) or other flue gas treatment is likely to be added at the time of retrofit then space for this should also be provided.

Note C5: A statement is required describing the space and required flue gas system configuration for retrofit requirements and how they will be implemented.

C6 Steam Cycle

Note C6: A statement is required giving the steam pressure at the steam turbine IP/LP crossover (or other steam extraction point), together with a description of any post-retrofit equipment modifications/additions. It should be demonstrated that the steam cycle could be operated with capture using solvent systems with a range of steam requirements. The energy penalty involved in such steam extraction should be estimated and compared to theoretical minimum values (i.e. for extraction from a similar steam cycle that has been purpose-built for such steam extraction).

C7 Cooling Water System

The amine scrubber, flue gas cooler and CO_2 compression plant introduced for CO_2 capture increases the overall power plant cooling duty.

Note C7: A statement is required of estimated cooling water demands (flows and temperatures) with capture and how these will be met. It is expected that necessary space and tie-ins for cooling water supplies to post-combustion capture equipment will be provided and a description of these should be included.

C8 Compressed Air System

The capture equipment addition will call for additional compressed air (both service air and instrument air) requirements.

Note C8: A statement is required of estimated additional compressed air requirements together with a description of how these will be accommodated.

C9 Raw Water Pre-treatment Plant

Space shall be considered in the raw water pre-treatment plant area to add additional raw water pre-treatment streams, as required.

Note C9: A statement is required of estimated treated raw water requirements together with a description of how these will be accommodated.

C10 Demineralisation I Desalination Plant

A supply of reasonably pure water may be required to make up evaporative losses from the flue gas cooler and/or scrubber. Estimates of this water requirement should be made and space allocated for the necessary treatment plant (and an additional water source be identified if necessary).
Note C10: A statement is required saying which of the above are needed and in what quantity and also describing how the necessary provisions will be implemented

C11 Waste Water Treatment Plant

Amine scrubbing plant along with flue gas coolers (if appropriate) provided for post combustion CO_2 capture will result in generation of additional effluents.

Note C11: A statement is required giving estimated additional waste water treatment needs and describing how the necessary space and any other provisions will be provided to meet expected demands.

C12 Electrical

The introduction of amine scrubber plant along with flue gas coolers, booster fans (if required), and CO_2 compression plant will lead to a number of additional electrical loads (e.g. pumps, compressors).

Note C12: A statement is required listing the estimated additional electrical requirements and describing space allocation in suitable

locations for items such as additional transformers, switching gear and cabling.

C13 Plant Pipe Racks

Installation of additional pipework after retrofit with capture will be required due to the use of a large quantity of LP steam in the amine scrubbing plant reboiler, return of condensate into the water-steam-condensate cycle, additional cooling water piping and possibly other plant modifications.

Note C13: It is expected that provision will be made for space for routing new pipework at the appropriate locations. A statement identifying anticipated significant additional pipework and describing space allocations to accommodate these is required.

C14 Control and Instrumentation

Note C14: It is expected that space and provisions for additional control equipment and cabling will be implemented. A statement identifying anticipated additional control equipment and describing space and other provisions to accommodate these is required.

C15 Plant Infrastructure

Space at appropriate zones to widen roads and add new roads (to handle increased movement of transport vehicles), space to extend office buildings (to accommodate additional plant personnel after capture retrofit) and space to extend stores building are foreseeable. Consideration should also be given to how, during a retrofit, vehicles or cranes will access the areas where new equipment will need to be erected.

Note C15: It is expected that the provisions above will be implemented. A statement identifying anticipated requirements and describing how they will be met is required.

Other technologies for post-combustion capture

C16 'Essential' Capture-Ready Requirements: Post Combustion Amine Scrubbing Technology based CO_2 Capture

The capture-ready requirements discussed in this section are the 'essential' requirements which aim to ease the capture retrofit of Natural Gas Combined Cycle power plants with post combustion amine scrubbing technology based CO_2 capture.

Note C16: The provisions covered in Notes C1-C15 can be adapted to include other liquid solvent mixtures for CO_2 capture that can be shown to have a reasonable expectation of being commercially available at the time of retrofit and for which reliable performance estimates are already available. A statement on where the requirements for capture readiness for such solvents differ from those for amine capture with respect to all of the relevant sections C1- C15 above is required, together with any additional CCR features or other actions proposed, to be added as addenda to the responses to Notes C1-C15. If making the plant capture ready for other solvents conflicts with the CCR requirements for amine

scrubbing then the impact on retrofitting amine scrubbing should be estimated and stated and the reasons for giving the other solvent priority should be listed and justified.