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Tees CCPP Project

The Tees Combined Cycle Power Plant Project
Land at the Wilton International Site, Teesside

Carbon Capture Readiness Statement

The Planning Act 2008

Applicant: Sembcorp Utilities (UK)
Date: May 2018

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GLOSSARY

Abbreviation	**Description**
AFW	Amec Foster Wheeler
CCPP	Combined Cycle Power Plant
CCR	Carbon Capture Readiness
CCS	Carbon Capture Storage
CHP	Combined Heat and Power
CO_2	Carbon dioxide
DCO	Development Consent Order
DECC	Department for Energy and Climate Change
EPC	Engineer Procure and Construct
EU	European Union
GT	Gas Turbine
HRSG	Heat Recovery Steam Generator
HSC	Hazardous Substance Consent
IEA	International Energy Agency
IED	Industrial Emissions Directive
kg	kilogram
km	kilometre
kW	kilowatt
LP	Low pressure
m	metre
MEA	Monoethanol amine
MJ	Megajoule
Mtpa	Megatonne per annum
MWe	Megawatt electrical
MWh	Megawatt hour
NOx	Nitrogen oxides
NSIP	Nationally Significant Infrastructure Project
NSP	National Policy Statement
O2	Oxygen
PA 2008	Planning Act 2008
R&D	Research and Development
SCR	Selective Catalytic Reduction
SCU	Sembcorp Utilities
SoS	Secretary of State
TC	Teesside Collective
TVCA	Tees Valley Combined Authority

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1 INTRODUCTION

1.1 This document forms part of Sembcorp Utilities (SCU) application for a Development Consent Order (DCO), that has been submitted to the Secretary of State (SoS) for Business, Energy and Industrial Strategy, under section 37 of the Planning Act 2008 (PA 2008).

1.2 SCU are seeking development consent for the construction, operation and maintenance of a new gas-fired Combined Cycle Power Plant (CCPP) with a capacity of up to 1,700 MWe which will be located at the Wilton Site on the south side of the river Tees.

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

1.4 The DCO, if made by the SoS, would be known as the Tees Combined Cycle Power Plant Order.

SCU

1.5 Sembcorp provides vital utilities and services to major international process industry customers on the Wilton International site on Teesside. Part of Sembcorp Industries, a Singapore-based group providing energy, water and marine services globally, Sembcorp Utilities UK also owns much of the industrial development land on the near 2,000 acre site which is marketed to energy intensive industries worldwide.

Proposed Development Site

1.6 The Proposed Development Site is located in the south west of the Wilton International site, in the location of the previously demolished power station that was operated by GDF. The plant was, mothballed in 2011 and, because of its inability to compete with more efficient power stations; it was subsequently decommissioned and demolished between 2013 and 2015.

1.7 The entire site is owned by SCU, and is entirely within the administrative boundary of Redcar and Cleveland Borough Council.

1.8 The site has two existing substations, and existing natural gas supply. All other utilities will be connected within the limits of the Project site and in turn connect to the existing Sembcorp infrastructure.

1.9 The proposed plant would operate on natural gas and be constructed using advanced gas turbine combine cycle equipment with a net thermal efficiency of ~60%. As such the total CO_2 produced by power generating activities would total around 560 tonnes per hour (a maximum of 5 million tonnes per annum or 0.33 tonnes per MWh).

The Purpose of this Document

1.10 The document has been prepared in order to demonstrate that Carbon Capture Readiness (CCR) conditions can be achieved in respect of the proposed development, and to satisfy a requirement of the DCO.

1.11 The Department for Energy and Climate Change (DECC) published a Guidance Note in November 2009 detailing the requirements for a CCR report that accompanies planning application for power stations of greater than 300 MWe output. This DECC guidance note (reference 1) recommended that a CCR study should cover the following:

- Demonstration that sufficient space is available on or near the site to accommodate carbon capture equipment in the future
- A review of the available methods of capturing CO_2 from large combustion plants, and a description of the indicative capture method that would likely be proposed
- A technical and economic assessment of the feasibility of retrofitting such carbon capture equipment to the proposed plant.
- Identification of a possible pipeline corridor from the site to a storage location, and an assessment of the technical feasibility of the route.

- Identification of suitable storage sites with sufficient capacity to store the captured CO_2 over the lifetime of the plant.

1.12 This assessment identifies that the currently most suitable method of capturing carbon would likely be based on one of a number of post-combustion capture techniques. The proposed design of the Tees CCPP will accordingly follow the same post-combustion CO_2 capture methodology advocated by numerous other power plant developers and operators incorporating design features that enable flue gas, process steam and power to be directed to the CO_2 capture plant in the best way possible (should carbon capture equipment need to be retrofitted in future).

1.13 As required this assessment also shows that there is adequate space for a suitable method to be implemented. The plot Sembcorp has selected for Tees CCPP is over 22 acres in size. Sembcorp also own and operate suitable pipeline corridors that would allow movement of CO_2 from Tees CCPP to designated locations for onward transportation to final storage.

1.14 Further to the conclusions of this study there are no known technical or economic barriers to retrofitting Carbon Capture Storage equipment (CCS) to Tees CCPP when the appropriate market and regulatory conditions dictate this.

2 LEGISLATIVE BACKGROUND

EU Directive on Geological Storage of Carbon Dioxide

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

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

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

This is known as a 'CCR Feasibility Study'.

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

The Carbon Capture Readiness (Electricity Generating Stations) Regulations 2013

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

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

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

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

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

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

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

2.9 CCR Regulation 3(3) states that:

"If the Secretary of State -

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

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

Planning Policy

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

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

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

Department of Energy and Climate Change Guidance on Carbon Capture Readiness

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

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

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

3 RATIONALE FOR POST-COMBUSTION CCS

3.1 As reported elsewhere by many others, retro-fit of post-combustion capture of CO_2 from the exhaust gases is currently the favoured approach for CCS at a CCPP. In this respect, many of the forgoing considerations cited elsewhere lead to this conclusion applying for Tees CCPP.

3.2 Pre-combustion capture techniques are available. In the case of Tees CCPP these would essentially involve taking the natural gas fuel and processing it in a multi-step process to obtain separate streams of carbon dioxide (for onward transportation and storage) and hydrogen fuel (for combustion in the gas turbine).

3.3 In principle, there are advantages claimed for this approach most notably a lower efficiency penalty and potentially a smaller carbon capture plant footprint with corresponding reduced plot size requirement. However, with this approach, the CCPP's Gas Turbine (GT) equipment would need to be capable of burning a pure hydrogen fuel. While combustion of hydrogen in a GT is technically possible it has not been demonstrated with the advanced GT technology that will be incorporated into the Tees CCPP.

3.4 Oxy-Fuel is an approach that is linked to CCS. In this case fuel is fully combusted in high purity oxygen which has been separated from air. The combustor produces a stream of gas that has a relatively high concentration of CO_2. This can be stored with minimal further separation/purification. This technology is however not suitable for normal CCPP as the thermodynamics of the cycle and operating conditions of the equipment are very different such that a bespoke turbine would be required.

3.5 Given this and that a significant amount of up-front consultation would be required with the equipment vendors for pre-combustion CCS, assumptions for CCR for the Tees CCPP are based on post-combustion sequestration.

3.6 With the chosen approach, prior to the introduction of CCS, the CCPP will be able to operate in an optimal manner before and after installation of the CCS the CCPP avoiding additional technical considerations and/or risks for the operation of the gas turbines.

3.7 Should it become feasible to retro-fit pre-combustion CCS then this and any potential up-side benefits would be considered at the time. The production of hydrogen from natural gas would be entirely compatible with the Wilton site should the technical capabilities of hydrogen combustion in the selected gas turbines become feasible. Requirements for off-site transport and storage of the CO_2 would not be altered and so the smaller plant footprint and reduced plot size requirements would mean this approach is entirely feasible.

3.8 The technologies that are currently available for post-combustion capture of CO_2 from flue gases can be based on absorption, adsorption, membranes or cryogenics. Amine solvent based absorption methods are currently the most developed and most likely to be viable at the required scale for the CCPP if CCS is implemented.

3.9 Absorption of CO_2 involves the contact of exhaust gases with an aqueous solution of a suitable solvent, such as Mono Ethanol Amine (MEA). MEA has a strong affinity for absorbing CO_2 out of the exhaust gas phase and into solution with the liquid. Contact of exhaust gases with solvents like MEA results in absorption and removal of around 90% of the CO_2 from the exhaust gas. After contact with the exhaust and absorption of CO_2, the solvent is circulated to a regeneration system where it is heated to release the CO_2 from solution (once regenerated it is then sent back to the adsorption process).

3.10 The scale of process and engineering required to achieve efficient operation, low loss movement of exhaust gas and circulation of the liquid on the scale required for a CCPP is greater than anything we are aware of that has been demonstrated to date. In particular the CCS plant, in effect a very large chemical facility, has a requirement for a significant amount of energy to drive the process. As such there is significant interest in reducing environmental impact and energy requirements.

3.11 Accordingly, research and development activities are focused on finding new processes and working fluid variations that may achieve this. For example, there is interest in sterically hindered MEA, other proprietary Amines, chilled ammonia and the use of carbonate slurries. There is also interest in biological methods of CO_2 capture that could in principle reduce or negate the requirement for transport and off-site storage.

3.12 Within this context, assumptions for the CCS plant design have been based on the most proven method of CCS by absorption using Amine solvent. The Fluor Daniel Econamine FG technology is a good example of this type of process and has been demonstrated in small scale plants for natural gas processing and flue gas applications. Assumptions are taken from references 2, 3, 4, 5 and 6.

3.13 This work demonstrates that while an Amine based CCS system at Tees CCPP is feasible other options may also be compatible with the chosen location. Selection of the eventual process can therefore be made in the future, at the time the decision to implement CCS is taken.

4 CARBON CAPTURE PLANT - TECHNICAL CONSIDERATIONS & CO_2 CAPTURE PLANT

4.1 This section relates to the technical considerations and feasibility of retro-fitting carbon capture equipment at Tees CCPP. It will concentrate on post-combustion techniques that use amine solvents for the reasons set out above in preceding sections of this document. Where appropriate it will however provide comment where possible on the feasibility of pre-combustion techniques.

4.2 The technical complexity and feasibility of the general aspects of solvent based carbon capture from exhaust gases are covered in detail in a number of publications and are outside of the scope of this document. Focus will be restricted to considerations that relate to retro-fitting the CCPP.

4.3 Currently the technical considerations and to some extent challenges of the post-combustion (amine) carbon capture technology for natural gas fired CCPP relate to:

- Cooling and subsequent handling of large volumes of exhaust gas to remove relatively low concentration of CO_2.
  - The flue gas leaving the Heat Recovery Steam Generator (HRSG) of the CCPP must be cooled before reaching the absorber of the carbon capture plant.
  - Large volumes of gas mean that mass transfer within the carbon capture processes needs careful consideration from a flow path loss/performance point of view. Even small pressure losses cause power and efficiency penalties.
  - Large gas volumes result in large scale plant with large footprint.
- Relatively high concentrations of exhaust NOx in the presence of a relatively high O2 concentration can cause solvent contamination/degradation
  - NOx degrades amine to volatile nitrosaturated compounds that may cause a number of problems within the process (including increasing solvent slip to the environment) which would need to be addressed by purging and replenishing solvent (chemical waste).
  - The CCPP might therefore need to be equipped with a Selective Catalytic Reduction system (SCR) to reduce NOx concentration in the flue gas in order to reduce solvent waste.
- Energy use of carbon capture equipment
  - The process requires significant heat supply for solvent regeneration in a reboiler (solvent is heated to release CO_2 from solution)
    - Steam could be taken from the CCPP in the form of steam or another suitable process such as an auxiliary boiler
    - Where it is elected that steam is taken from the CCPP, careful consideration to the thermodynamic balance of the CCPP's steam cycle and equipment sizing/design must be given.
    - The use of heat in the carbon capture process reduces net efficiency of the CCPP
  - The carbon capture process requires a power supply for pumps, controls, cooling fans and booster fans.
    - The use of power in the carbon capture process reduces net efficiency of the CCPP
  - CO_2 compression to pipeline pressure (potentially to supercritical pressures) requires power for the compressors.
    - The use of power in the CO_2 compression process reduces net efficiency of the CCPP
  - In addition to exhaust gas cooling (prior to exhaust gas entering the carbon capture plant) the carbon capture plant also requires a large cooling system that provides cool solvent to the absorber.

4.4 There are consequently process requirements and important integration considerations associated with retro-fitting the carbon capture equipment to the CCPP.

4.5 Tees CCPP will be specified with dry low NOx burners. Space will be allocated to allow a post combustion NOX abatement system to be retrofitted within the HRSG, e.g. Selective Catalytic Reduction (SCR). This should be sufficient to address the solvent degradation.

4.6 A horizontal gas path type HRSG will likely be selected for Tees CCPP. This will allow the most practical means of extracting the exhaust gas and then ducting it over to the CO_2 capture plant. The retro-fit will include bypass dampers to be inserted that allow the CCGT to operate independently of the CO_2 capture plant, for example during start and stop periods or in the event that CO_2 capture plant is out of service and the CCPP must run.

4.7 Cooling of the exhaust gases prior to entering the carbon capture plant absorber can be achieved with cooling water either indirectly via installation of a surface heat exchanger or directly via contact with cooling water spray or film. Direct contact with cooling water is the preferred approach of many CCPP developers.

4.8 Water is continuously circulated in the direct contact cooling system. As the water being circulated removes heat from the exhaust gases, the temperature will rise and so must be cooled before each pass through the exhaust gases. Cooling can be achieved using one of a number of conventional cooling tower system techniques that would be installed at the time of the retro-fit.

4.9 The additional pressure drop resulting from passing the flue gases through the absorber and associated duct work would ordinarily cause a back pressure on the gas turbine that would affect the performance and control of the CCPP. To counteract this, a booster fan would be installed to compensate for this.

4.10 Steam required to operate the carbon capture plant can be provided by the CCPP, ideally by extraction from a suitable location in the steam cycle process - likely IP turbine exhaust (LP turbine inlet). Design decisions must however be considered carefully as the levels of steam extraction from the process required for CO_2 capture on a CCPP are in the region of 40% to 50% of the steam that would normally be provided to the inlet of the Low Pressure (LP) turbine. The issue of the steam system design is both technical and economic in nature requiring careful consideration. The main options are as follows:

- Fit a standard/normal size LP cylinder from the outset and extract steam from CCPP after CCS retro-fit
  - operates optimally (lower back pressure) up until CCS retro-fit
  - operates sub-optimally (higher back pressure) after CCS is implemented
- Fit a smaller LP cylinder from the outset and extract steam from CCPP after CCS retro-fit
  - operates sub-optimally (higher back pressure) until CCS retro-fit is implemented
  - operates optimally (lower back pressure) after CCS retro-fit
- Fit standard/normal size LP cylinder from the outset and modify/resize LP turbine prior to CCS retro-fit.
  - operates optimally (lower back pressure) up until CCS retro-fit
  - operates optimally (lower back pressure) after CCS retro-fit
- Fit a standard/normal size LP cylinder from the outset and after retro-fit of CCS provide steam from an alternative source:
  - Alternative source in place of extracting steam from the CCPP steam cycle (CO_2 emissions from the alternative system to also be captured)
  - A stand-alone auxiliary boiler
  - Separate Combined Heat and Power (CHP) plant

4.11 The preferred options for Sembcorp would be to fit a standard/normal size LP turbine from the outset. At the time of the CCS retro-fit Sembcorp would conduct a study to determine the best option. In all likelihood, this would be a re-size of the LP turbine or provision of steam and power from a stand-alone CHP. In respect of the latter, Sembcorp operate a variety of other CHP assets and utilities infrastructure in the interests of energy intensive industries located on the Wilton International site. This may provide an optimized solution.

4.12 The cooling duty for the flue gas cooler, solvent cooling, and CO_2 compression plant have been estimated. An additional 50% cooling duty is likely to be required on top of the base CCPP requirements. The bulk of the initial CCPP cooling requirement will be provided by Hybrid Cooling Towers. Although the CCPP cooling requirements will reduce after the retro-fit of CCS (steam to the LP turbine will reduce) this cooling capacity will not become available to the CCS plant. In this case the CO_2 capture plant cooling duty will be provided by new equipment.

4.13 It will be necessary to store solvent on-site. Usage and therefore storage capacity would need to be determined during the detailed design phase of the CCS facility. It is anticipated that a bunded storage system with a capacity of a few hundred tonnes will be required and an unloading facility. The solvents are normally purchased in concentrated form and stored in the tank systems under a nitrogen blanket with a carbon filter on the vent. The solvent would be diluted with water to an appropriate concentration when added to the process.

4.14 There would be no storage of CO_2 on site. The compression equipment would pressurize the CO_2 to the pipeline pressure and it would leave the site shortly after being captured.

4.15 The CO_2 capture equipment will require many of the same plant auxiliary services such as demineralized water, raw water, fire-fighting and compressed air equipment that are also required by the CCPP. If advantageous these will be provided by common systems but otherwise will be stand-alone, located adjacent to the CO_2 capture equipment. Sembcorp has significant capacity to meet the necessary raw water and demineralised water requirements of Tees CCPP. Raw water and demineralised water use is not expected to be significant prior to the retro-fit of CCS.

4.16 The amine scrubbing plant and direct contact exhaust cooler will generate some effluents. These effluents will be treated within a dedicated waste water treatment plant within the CO_2 capture plant and if necessary discharged into the existing Wilton site drainage system. Waste from any process such as amine degradation will be treated on-site where possible or otherwise taken off-site for appropriate treatment.

4.17 Retro-fitting post combustion CCS is likely to reduce the output of Tees CCPP by up to around 15% or 250MW. This estimate is based on the assumption that Tees CCPP produces 560t/h of CO_2 in flue gas, 90% of which is recovered in the CCS and parameters from refs 4, 5 and 6. This reduction in net output will be partly due to additional auxiliary power demands of the CCS plant (about 40% of the reduction stated) and partly due to the heat demands of the CCS plant (60% of the reduction) assuming this heat is taken in the form of LP steam from the CCPP steam turbine.

4.18 The main electrical energy consumers of the CO_2 capture plant are the exhaust booster fan, CO_2 compressors, solvent pumps, cooling water pumps and cooling tower fans. The total estimated demand for electrical power of a retro-fit CCS system would therefore be up to 100MWe. This means that the specific power consumption for the main and auxiliary CCS plant systems is approximately 0.18MWh of electricity per tonne of CO_2 captured.

4.19 As part of the development SCU will be installing a 180MVA Feeder between the Generator and the connection to the National Grid Greystone Substation (please note there will be one Feeder per Generator)

4.20 This feeder(s) will provide sufficient power for any future carbon capture plant as the total estimated demand for electrical power of a retro-fit CCS system would only be up to 100MWe for two phases.

4.21 If heat for the CCS plant is to be taken from the CCPP by the extraction of LP steam, the CCPP steam turbine power would reduce by up to about 150MW i.e. causing a further reduction in electrical net output of 0.27MWh per tonne of CO_2 captured. In heat terms, the latter is reflective of a reboiler duty of about 3.3 to 4 MJ/kg of CO_2 (0.9 to 1.1 MWh thermal per tonne CO_2 captured).

4.22 Sembcorp operate a variety of large CHP assets, a number of which operate on renewable or waste fuels. Demand will either be supplied by Tees CCPP, or potentially from a dedicated CHP plant or a combination of both.

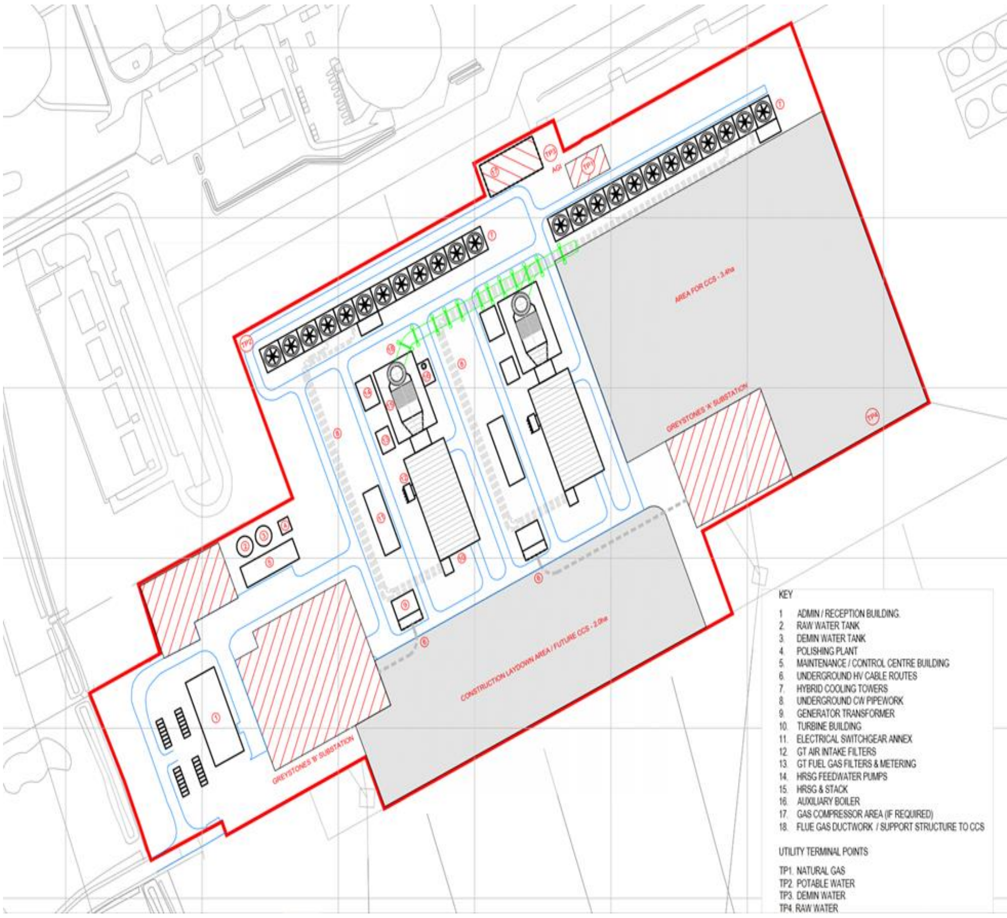
4.23 In terms of spatial requirements, the International Energy Agency (IEA) have previously estimated that an area of 250m x 150m (9.3 Acre or 3.7 Hectare) is required for a CCS plant fitted to a 785MWe CCPP based on two gas turbines (reference 2). The area required for Tees CCPP if simply scaled from this estimate would not be available at the selected site. Tees CCPP would be a 1,700 MWe combined cycle unit and so require up to 20 Acre (8 Hectare) for all of the CCS plant.

4.24 It is however recognized by many studies (e.g. reference 3 - Assessment of the validity of - Approximate minimum land footprint for some types of CO_2 capture plant, Florin and Fennell, Imperial College, October 2010) that such a simple scaling on power output leads to a significant over estimate of the plot size requirements for CCS. The number of exhaust streams and relative gas volumes would have a stronger bearing on the plot size (rather than scaling on power output). In this respect the plot size requirement is likely to be no more than 25% greater than the requirement identified in the IEA work (i.e. 11.6 Acre or 4.6 Hectare). The total area available for CCS at Tees CCPP is 5.4 Hectare, split between two areas - 3.4ha to the west of the generation equipment and 2.0ha to the south of the generation equipment, both within the Order limits.

4.25 Given the multi-stage process requirements of post-combustion Amine solvent based absorption carbon capture - absorption, stripping, cooling, compression etc. although the two areas are not shown as being connected, the required interconnectivity (e.g. piping, power) between process stages can be achieved via a pipe bridge or underground ducts between the two areas which are shown in CCR Statement Figure 1 Tees CCPP High Level Layout.

4.26 Further discussion on this matter indicates that even this may be an over estimate (reference 3).

Figure 1 - Tees CCPP High Level Layout



4.27 Should pre-combustion CCS be selected then the land requirement for the CCS plant would be less than this. The requirement for some items such as exhaust duct work, exhaust gas cooling and booster fan would be avoided. The scale of the carbon capture plant and requirement for solvent would also be reduced.

4.28 Plant for CO_2 compression to pipeline pressure would be the same. The plant would however require additional items for reforming the natural gas and storing some hydrogen fuel. Flexibility of layout would be improved (adjacency requirement of CCS equipment would not be as acute due to removal of requirement to move large volumes of exhaust gas).

4.29 Therefore SCU are satisfied that that given land footprint for CO_2 capture plant and the proposed layout of Tees CCPP the total area (5.4ha) of the Tees CCPP development allocated for future carbon capture equipment retrofit is sufficient.

5 CO_2 PIPELINE TRANSPORTATION & STORAGE

5.1 Teesside has well publicized and documented plans for the implementation of a 15 million tonne per annum CCS network. The CCS network is proposed by Tees Valley Combined Authority (TVCA) and supported by Teesside Collective (TC) who are a cluster of multi-national companies which includes Sembcorp Utilities.

5.2 The feasibility of a CCS network has been examined in relative detail by Amec Foster Wheeler (AFW) and various proposals for implementation have been outlined. The Wilton site location for Tees CCPP is well placed to connect with any of the proposed variants of the CCS network allowing captured CO_2 to be transported to the chosen off-shore storage site via pipeline.

5.3 Sembcorp has a number of key pipeline corridors to both the north and south of the river Tees which would enable CO_2 from Tees CCPP to connect with Teesside's CCS network. These corridors run mainly on industrial land at acceptably low proximity to residential locations.

5.4 Current proposals favour a beach landing to the south of the Tees at a location that can easily be reached by corridors that include tunnels under the river Tees connecting the northern and southern industrial areas which could be used for the transport of CO_2 from Tees CCPP if the beach landing for the off-shore network was ultimately located to the north.

5.5 A post combustion CO_2 capture plant, operating at a 90% capture rate, retrofitted to Tees CCPP would capture approximately 500 tonnes of CO_2 per hour with the plant operating at maximum output. As the Teesside CCS network proposes to connect the beach landing to either National Grids Area 5 storage area in the Southern North Sea (via a 15Mtpa/154km off-shore connection) or Shell's Goldeneye storage area (via 15 Mtpa/433km off-shore connection) there should be acceptable capacity to receive Tees CCPP CO_2.

5.6 Further to this, a more detailed study to assess the viability and cost effectiveness of the CO_2 pipeline and routes dedicated to Tees CCPP would only have value if it were carried out closer to the time of implementation. However, due to the work undertaken by AFW on the Teesside CCS network and existence of pipeline corridors/infrastructure, it is reasonable to state that there are no technical barriers that would prevent the development of a CCS pipeline in future.

5.7 It would also be reasonable to state that as Teesside has industrial infrastructure and is geographically well located to potential storage sites under the North Sea, the cost effectiveness and economics of CCS would be competitive with other locations.

6 CCS RETROFIT - SIMPLE ECONOMIC ASSESSMENT

6.1 This section provides an indication of the relative economics of retrofitting CCS to Tees CCPP. This is based largely on public domain information drawn from studies carried out by a number of organizations including the International Energy Agency Greenhouse Gas R&D Programme (reference 4). There have unfortunately been no full-scale CCS plant demonstrations on a CCPP to refer to. Therefore, the estimated costs and performance impacts are considered to have an appropriate level of detail and accuracy for the purposes of this assessment.

6.2 Information from reference 4 was used to provide a cost range of 400 to 600 £/kW (referenced to CCPP unmodified gross output) for carbon capture and compression plant sized to match the output capacity of Tees CCPP. In this respect, the assessment for Tees CCPP is based on a future scenario where local infrastructure receives CO_2 into a storage network for a cost. The cost of the carbon capture facility would therefore be £680m to £1,020m. Based on reported information available in the literature the range depends on the selection of the solvent.

6.3 These capital costs are considered to be reflective of total equipment supply under an Engineer Procure and Construct (EPC) contract with an appropriate equipment supplier. Given the broadness of these costs, expenditure is assumed to include for "owner costs" and other "soft costs" which includes planning and development costs.

6.4 Furthermore, for the sake of a simple analysis, the annual capital recovery rate might be £68m to £102m per annum.

6.5 Operational costs considered include solvent replacement, ancillary electricity consumption (carbon capture plant and compression), steam consumption, carbon capture specific maintenance costs.

6.6 For simplicity, costs of between £20m and £50m per annum are assumed for all annual maintenance, work force costs, licenses, insurances etc. This is based on an assumed range of 2.5% to 5% of plant CAPEX.

6.7 The combined annual cost of capital and maintenance would therefore be between £88m and £152m per annum.

6.8 In line with the information available, the variable costs are assumed to be dominated by solvent usage. Information in reference 6 indicates a solvent cost of around £5 per tonne of CO_2.

6.9 Assuming a plant utilization of around 60%, the CO_2 captured at Tees CCPP would be in the region of 2,700,000 tonnes per annum. Consequently, the cost of capturing CO_2 will be in the region of £40 to £60 per tonne. In terms of electricity, this cost would be equivalent to 12 to 18 £/MWh.

6.10 According to ref TVU Pre-Feed Study, the CO_2 storage network tariff might be in the range £4 to £7 per tonne.

6.11 These results compare well with recent CCS economic assessments (references 4 and 8).

6.12 These results are high level estimates, and not developed to the level of detail or cost certainty to support an investment case.

7 HEALTH AND SAFETY ASSESSMENT

CO_2

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

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

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

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

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

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

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

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

7.8 Solvent

7.9 When carbon capture becomes viable, detailed design for the carbon capture plant will include the solvent to be used and the quantity of solvent to be stored on site. At this time there will be an assessment of the solvent, its properties and whether it is classed as a hazardous substance and a hazardous substance consent is required.

8 CONCLUSIONS

8.1 Subject to assumptions, which includes the emergence of a CO_2 network, the appropriate market and regulatory conditions, this report demonstrates the technical feasibility and economic conditions for retrofitting CCS to Tees CCPP.

8.2 Information and details regarding plans to implement a CO_2 network in Teesside (with off-shore storage of 15Mtpa) are in the public domain. Further to this, potential viable pipeline corridors on the Wilton site for the Tees CCPP are also shown in figure 2 in the Appendix. The CO_2 pipeline routes from Teesside Collective Blueprints are shown in figures 3 to 5.

8.3 The method assumed/proposed for capturing CO_2 in this assessment has been post combustion (exhaust gas clean up). Subject to the emergence of suitable gas turbine combustion technology, carbon capture could also be based on pre-combustion techniques. Given the industrial nature of the Wilton international site, neither would present issues if viable elsewhere.

8.4 Subject to the accuracy of the assumptions used, adequate space for this plant is available on the Tees CCPP site to accommodate a future CO_2 capture plant.

Review

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

9 REFERENCES

1. Carbon Capture Readiness - A guidance note for Section 36 Electricity Act 1989 consent applications, DECC November 2009.
2. Retrofit of CO_2 Capture to Natural Gas Combined Cycle Power Plants, IEA 2005.
3. Assessment of the validity of - Approximate minimum land footprint for some types of CO_2 capture plant, Florin and Fennell, Imperial College, October 2010.
4. CO_2 Capture at Gas Fired Power Plants, Parsons Brinckerhoff (for the IEAGHG), July 2012.
5. Parametric study and benchmarking of NGCC, coal and biomass power cycles integrated with MEA-based post-combustion CO_2 capture, Berstad, Arasto, Jordal, Haugen Energy Procedia vol. 4(2011).
6. Thermodynamic Analysis on Post Combustion CO_2 Capture of Natural Gas Fired Power Plant, Amrollahi, Ertesvåg, Bolland, International Journal of Greenhouse Gas Control May 2011.
7. A techno-economic analysis of post-combustion CO_2 capture and compression applied to a combined cycle gas turbine: Part I. A parametric study of the key technical performance indicators, Alhajaj, Mac Dowell, Shah 2016.
8. A techno-economic analysis of post-combustion CO_2 capture and compression applied to a combined cycle gas turbine: Part II. Identifying the cost-optimal control and design variables, Alhajaj, Mac Dowell, Shah 2016.

APPENDIX - FIGURES 2 - 5

Figure 2 - Sembcorp corridors on Teesside

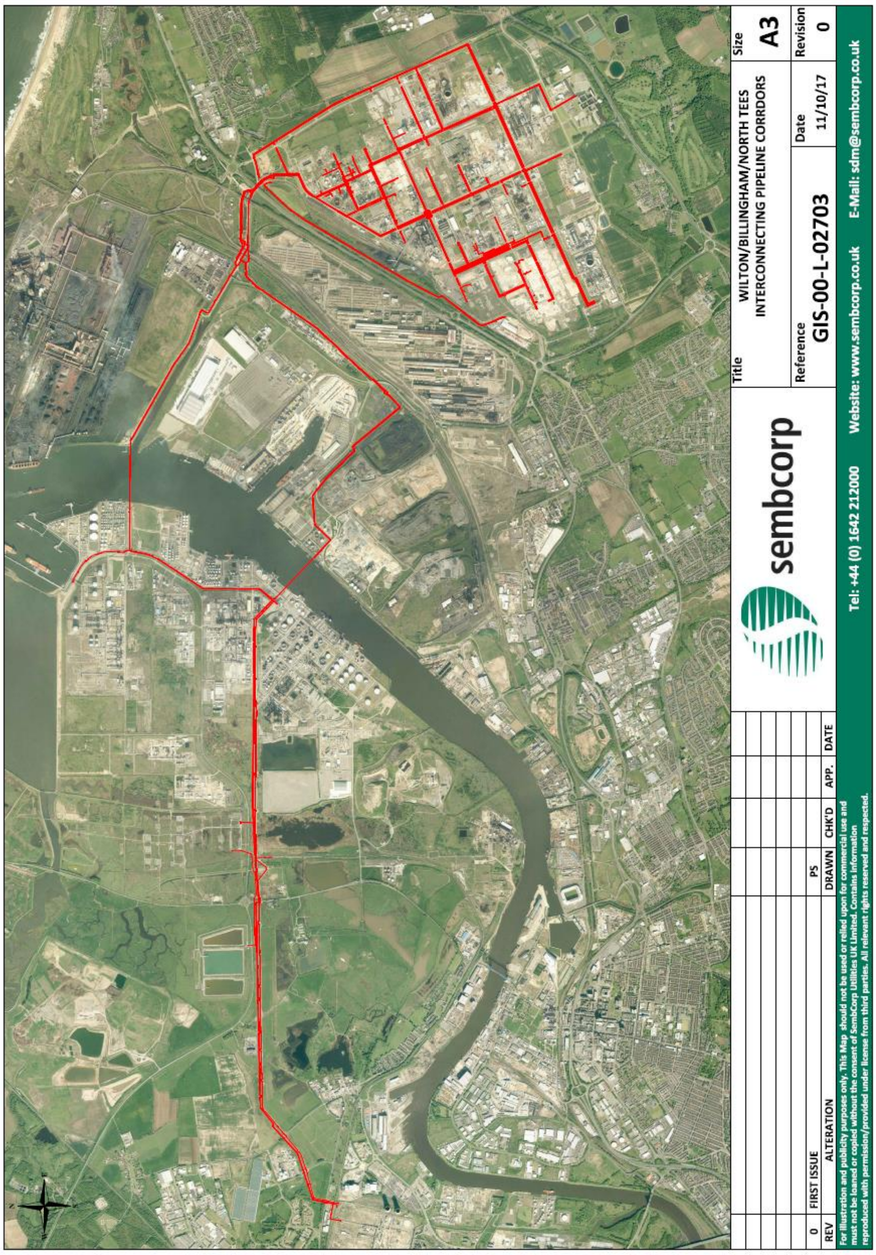


Figure 3 - CO2 Pipeline Routes from Teesside Collective Blueprints

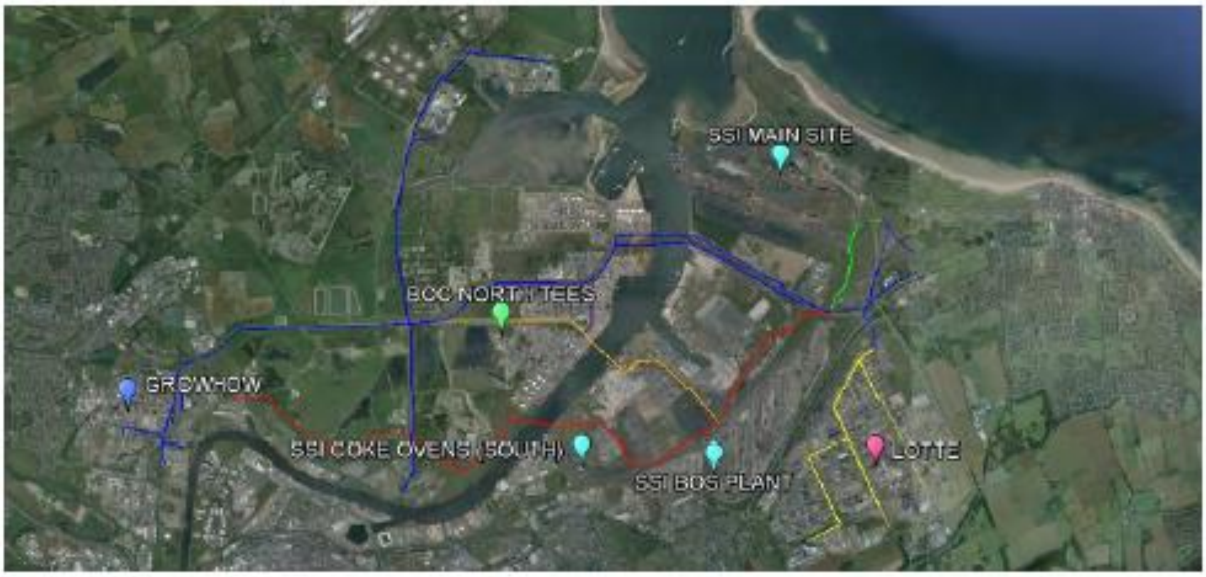


Figure 4 - Map showing the possible destinations for the Teesside Industrial CO_2

Figure 5 - Route from Teesside to the Shell Goldeneye Storage Complex