



Programme Area: Carbon Capture and Storage

Project: Thermal Power with CCS

Title: Template Plant Specification

Abstract:

The purpose of the Template Plant Specification is to:

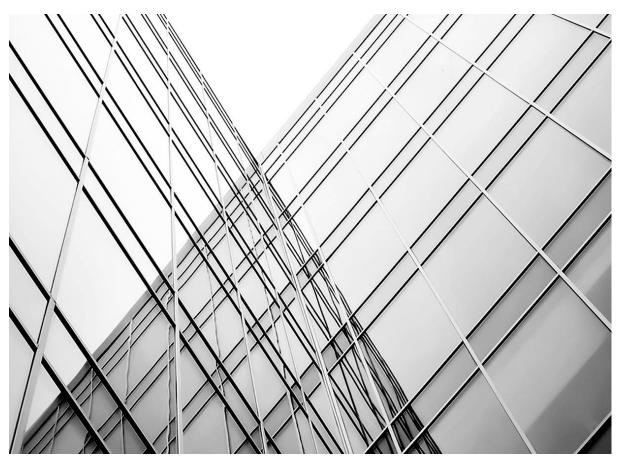
- Define the process scheme for the project.
- Provide sufficient input to location selection (plant footprint, inflow connections, out flow connections, utility connections), modelling (plant basis), and estimating (scope definition, contracting basis).
 - Provide a convincing basis to a range of stakeholders.

The intention is to mimic, at a high level, an Enquiry Specification for an EPC Contract as this would provide a grounding for the work to be undertaken in WP3 (Cost Estimating). The plant basis in this document is of up to five largely independent trains, each comprising a latest generation (H/J class) combined cycle gas turbine, state of the art amine capture and compressor.

Context:

The ETI's whole energy system modelling work has shown that CCS is one of the most cost effective technologies to help the UK meet its 2050 CO2 reduction targets. Without it the energy system cost in 2050 could be £30bn per annum higher. Consequently, ETI invested £650,000 in a nine month project to support the creation of a business case for a large scale gas with CCS power plant, to include an outline scheme and a 'template' power plant design (Combined Cycle Gas Turbine with post combustion capture), identify potential sites in key UK industrial hubs and build a credible cost base for such a scheme, benchmarked as far as possible against actual project data and as-built plant. The ETI appointed engineering and construction group SNC-Lavalin to deliver the project working with global infrastructure services firm AECOM and the University of Sheffield's Energy 2050 Institute.

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Template Plant Specification

Doc Number: 181869-0001-T-EM-SPE-AAA-00-00001

Revision A03

ETI Number: D2.1

Version 2.0









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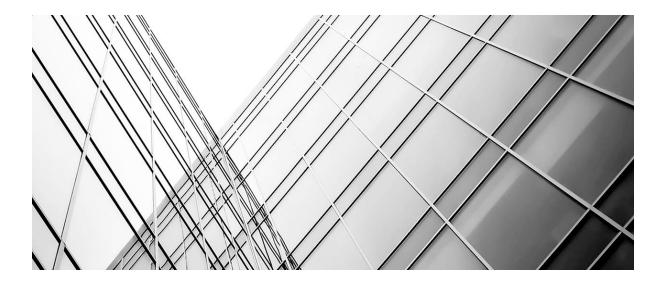
This document has been electronically checked and approved. The electronic approval and signature can be found in FOCUS, cross referenced to this document under the Tasks tab, reference No: T072873.

A03	21-DEC-16	Interim for ETI Review (Incl Peer Review Comments)	M.W.	K.S.	S.B.	M.W.
A02	13-DEC-16	Issued for Peer Review	M.W.			
A01	11-NOV-16	Interim Submission for Review	M.W.	K.S.	S.B.	M.W.
REV	DATE	ISSUE DESCRIPTION	BY	DISC CHKD	QA/QC	APPVD

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Introduction

The purpose of the Template Plant Specification is to:

- › Define the process scheme for the project.
- Provide sufficient input to location selection (plant footprint, inflow connections, out flow connections, utility connections), modelling (plant basis), and estimating (scope definition, contracting basis).
- > Provide a convincing basis to a range of stakeholders.

The intention of the document is to mimic, at a high level, an Enquiry Specification for an EPC Contract as this would provide a grounding for the work to be undertaken in WP3.

Project Description

Provision 1 of the Climate Change Act 2008 states that "It is the duty of the Secretary of State to ensure that the net UK carbon account for the year 2050 is at least 80% lower than the 1990 baseline."

The UK Government's plans are consistent with the Paris Agreement in December last year, where the countries of the world agreed to an increased ambition to tackle climate change. In particular, they agreed an aim to limit the rise in global temperature to well below 2°C, with efforts to hold it to 1.5°C. The Agreement demonstrates the need for countries to work together to meet mutually agreed ambitions.

The ETI's energy system modelling work has shown that Carbon Capture and Storage (CCS) is one of the most potent levers to help the UK meet its 2050 CO₂ reduction targets: without CCS the energy system cost in 2050 could be £30bn per annum higher.

With planned retirements of the UK's existing fossil fuel and nuclear fleet, there will be a growing need for new, dispatchable power through the 2020s, with low CO₂ intensity to meet tightening carbon budgets. Withdrawal of funding from the Commercialisation Programme in 2015 left the UK without any explicit funding mechanism for developing CCS in the UK. Since the CSR decision, the ETI has carried out a range of different analyses around potential ways forward. They confirm that the most cost-effective and secure way to meet these needs is to move forward as soon as reasonably possible with a strategically-placed, large-scale gas with CCS power project. Delay in the implementation of CCS could cost £1 – 2bn per annum in the 2020s, rising to £4 – 5bn by 2040. Capturing and storing industrial emissions only becomes practically and economically feasible once infrastructure is put in place: this can only be reasonably done with large scale power with CCS projects. The Committee on Climate Change (CCC) has also commissioned work in this area concluding that "continuous rollout of CCS power generation will drive savings via lower financing costs and development of supply chains." (POYRY, 2016) As well as the whole-system benefits of CCS, the ETI's latest analysis suggests that the levelised electricity costs of a well-designed power with CCS project could be attractive against other low-carbon alternatives. The ETI's analysis aligns with the Lord Oxburgh report "even the first CCS projects can compete on price with other forms of clean electricity." (Storage, 2016)

The UK Government retains the belief that CCS could play a crucial role in the future energy system. However, stakeholders in CCS will need compelling evidence of the business case for a power with CCS project. As a consequence the ETI has identified a revised programme for the 'Generic Business Case' aspect of the Thermal Power with CCS (TPwCCS) project, which is the subject of this RfP. This involves developing an outline scheme and 'template' power plant design (CCGT with post combustion capture), identifying potential sites and building a credible cost base for such a scheme, benchmarked as far as possible against actual project data and as-built plant

The key objective of the Project is to enhance the evidence base on the realistic cost and performance of a large scale, low-risk CCGT with CCS Scheme, with such cost and performance being convincing to a wide range of stakeholders. This will be achieved by bringing together best available design information and benchmarking data for such a Scheme. More specifically the Project will:

- Produce an outline power scheme and template CCGT plant specification;
- Identify the most promising location options, capable of development of a large scale (ultimately 2GW plus)
 Gas CCGT with CCS project, which minimises development cost/risk and transport & storage costs;
- Develop robust P50 and P90 total project costs for a 'template' CCGT with best-in-class amine, post-combustion CCS, located at the selected locations, benchmarked against actual project costs. Produce probabilistic cost models of the complete Scheme costs (where P50 and P90 are statistical confidence levels);
- Determine realistic operating costs for such a Scheme, taking into account its likely operation within a future energy system.

"As the first full-scale application of carbon capture and storage (CCS) to a power plant, the opening of Canada's Boundary Dam plant in 2014 was heralded by the emerging CCS industry as a landmark moment which would lead to similar developments worldwide. However, other commercial demonstrations of the technology in power generation have so far remained limited to the Petra Nova and Kemper Country projects under construction in the USA – both scheduled to start early next year. Like Boundary Dam, these projects share the favourable circumstances of a cheap and plentiful coal supply and a market for CO₂ for use in enhanced oil recovery. Meanwhile in Europe, where neither of these drivers are usually present, the development of CCS has largely

stalled, with the cancellation of the UK CCS demonstration programme late last year putting an end to one of the last major prospects in the region." (Toby Lockwood, 2016)

However, whilst the 1st generation Carbon Capture plants have demonstrated the technology, the application of CCS has been too expensive for most of the world's energy markets: "cost-of-electricity increase of up to 80% and CO₂ capture price of US\$60/t estimated for state-of-the-art technologies." (Toby Lockwood, 2016) A more cost effective implementation is required. The Generic Business Case incorporates the following approaches in order to reduce the cost of deployment of CCS in the UK Energy Market:

- > Economies of scale (approximate 3 GW plant size)
- Higher efficiency gas turbines (H & J Class)
- 'State of the Art' amines that have properties that require less electricity output penalty overall (combination of energy requirements and the highest possible stripping temperature to minimize compression energy)

Outline Scheme Design

The Generic Business Case aims to capture around 10 million tonnes of CO_2 per annum from Combined Cycle Gas Turbines (CCGT). The overall plant configuration is expected to be as follows:

-) Gas inlet to the CCGT's:
- 5 GasTurbines (GT) Nominal total capacity 2.5 GW (each 500MW);1
- 5 Heat Recovery Steam Generators (HSRG);
- 5 Steam Turbines (ST) Nominal total capacity 1000 MW (each 200 MW); 1,2
- > Flue gas treatment, with Selective Catalytic Reduction (SCR), for NOx removal;
- 5 Carbon Capture (CC) Units, i.e., there will be one CC Unit for each CCGT train;
- > 5 CO₂ Compressors;
- CO₂ pipeline, with valve stations, for dense phase CO₂ transport to the shoreline;
- > Shoreline compressor station, if required;
- → Subsea CO₂ pipeline; and
- › Offshore Platform.

The Outline Scheme can be seen on the Block Flow Diagram - Outline Scheme Design at Plant Level, document reference 181869-0001-D-EM-BLK-AAA-00-00001-01 (attached).

Notes

- 1. Nominal figures are unabated.
- 2. Steam Turbine nominal value may be adjusted during modelling works.

Major Process Hazards

The following major plant hazards have been identified with regards to the Outline Scheme Design:

Carbon Dioxide (CO₂)

Danger to life from asphyxiation or toxicity of escaping CO₂

Design in accordance to prevailing wind conditions

Asphyxiation from approx 50% v/v in air. Toxicity > 15% v/v in air (50% fatalities for 1 minute exposure time) (Dr Peter Harper, 2011)

Design to limit inventory of CO₂ in onshore plant, pipeline segments, and offshore

Design to maximise natural ventilation and dispersion in order to minimise potential CO₂ accumulation

Design to contain CO₂ (e.g. international design codes)

CO₂ detection, alarm, isolation, and blowdown system

Major Accident Hazard: The hazard range for an instantaneous release from storage may be in the range of 50 to 400 m with large, cold, liquid phase storage producing the larger distances. The hazard range for a continuous release through a 50 mm hole may be up to 100 m. (Dr Peter Harper, 2011)

Risk of structural collapse following large release due to cooling effects and dry ice cold jet effects. (Connolly & Cusco, 2007)

Danger to life from the explosion of escaping natural gas

Design in accordance to prevailing wind conditions

Design to limit inventory of natural gas on CCGT plant

Design to maximise natural ventilation and dispersion in order to minimise potential gas cloud and explosive atmosphere accumulation

Design to limit potential point of release (e.g. minimisation of flanges)

Design to contain gas (e.g. international design codes)

Fire and Gas detection, alarm, isolation, and blowdown system

Fire protection system

Design to minimise sources of ignition (ATEX)

Design manned buildings in area of hazard to be blast proof









HV Electricity



Hazard from an electric shock when working on HV electrical

This may result in fatality

Electrical supplies shall be isolated and locked off before work commences

Isolations and subsequent works shall be carried out under a permit to work system

Terminals / cables shall be tested before work commences

Step back - check stop/start buttons are deactivated, isolated and/or locked off

Electrical protection systems to break circuits on fault detection

Key Cost Trade Offs

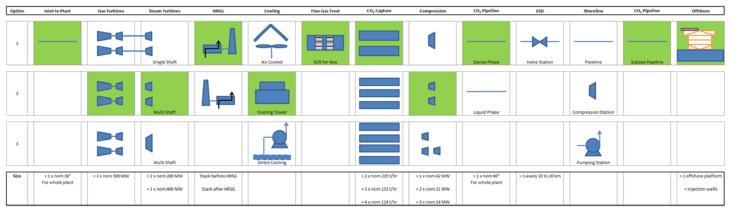
The ETI's financial modelling shows that use of debt is much better than marginal efficiency gain. The selected technology and plant scheme design must be bankable.

It is assumed that a Contract for Difference (CfD) would be available for the CCGT + CCS Scheme. The CfD only pays if the scheme works and CO₂ is sequestered: therefore, overall scheme reliability is an important driver for the project.

The Business Drivers agreed with the ETI are:

- Maximum Reliability is most important because CfD for the scheme will only pay if CO2 is sequestered.
- > Minimum CAPEX is next most important driver in order to make the scheme feasible to build.
- > Stepless flexibility is not so important. Preliminary modelling being undertaken for the ETI indicates that new CCGT + CCS would have 70% dispatch. (Note: Dispatch is the process of selecting the electricity generation facilities and their output to meet the system load, at the lowest possible cost).
- 'Chunky' flexibility e.g. allowing each train to be switched on and off would be an advantage because CCGT + CCS would be ahead of Nuclear and Wind in being switched off in dispatch analysis.

A range of options were considered for the high level scheme design against the agreed business drivers. The following chart shows those options which were considered and the selected options highlighted in green. (Refer to Attachment 2 for a larger copy of the following chart).



Cost Trade Offs

There were a number of options where there was a trade off in costs between options:

Steam Turbine

Heat recovered from the Combustion Turbine (CT) exhaust gases is used to generate steam. The steam is used to generate electrical power from a steam turbine (with some of the steam being extracted for the Carbon Capture plant). A typical arrangement is to have the heat from multiple gas turbines being used to generate steam for one steam turbine – the most common arrangement being 2 combustion turbines to 1 steam turbine (described as a 2+1 arrangement). The European Market has tended to have each combustion turbine to have a steam turbine generation set (described as a 1 + 1 arrangement).

The minimum CAPEX solution is a 2+1 arrangement (2 Gas Turbines with Heat Recovery Steam Generators which supply steam to 1 Steam Turbine).

The best solution to meet the key business driver of highest reliability is a 1+1 configuration (1 steam turbine for each combustion turbine)

The higher CAPEX for the 1+1 configuration is a result of an additional Steam Turbine with Generator, additional condenser, additional civil works, a larger turbine hall, additional labour for mechanical, electrical, and

instrumentation installation. A high level estimate of impact is +£44M per pair of CTs or +£22M per train. Allowing for 5 trains the total high level estimate impact would be £110M.

A 1+1 configuration provides better efficiency – calculations runs for class H show a 0.1% better efficiency than 2+1. A 1+1 also provides a more simple train building block. i.e. Each train becomes:

-) 1 Combustion Turbine
- › 1 Heat Recovery Steam Generation
-) 1 Steam Turbine
- Carbon Capture and Compression

CCGT Configuration

CCGT's can be supplied as single shaft units or multi shaft units.

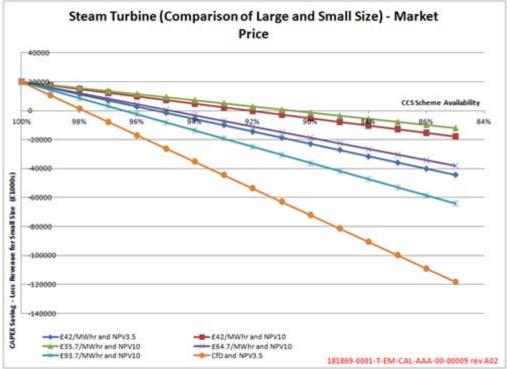
A single shaft unit has all the train rotating together – combustion turbine, generator, and steam turbine. There is typically a clutching arrangement to decouple the steam turbine for start-up and off design operation.

There is typically a small cost increase for a multi-shaft arrangement as this requires an additional generator and some additional auxiliaries. This has been estimated as roughly £3M per train: however, this is very site dependent as a single shaft solution requires a more complex foundation arrangement, a clutch, and a double ended generator.

The multishaft solution allows a more flexible layout as the steam turbine building can be located separately to the gas turbines. i.e. A single shaft unit would extend the length dimension within the CCGT area of the plant: whereas a multi-shaft arrangement allows side by side arrangement utilising the plot space more efficiently (refer to Plant Footprint Section for information).

Oversized Steam Turbine

The project reviewed the sizing the steam turbine generators. The additional CAPEX was evaluated against the opportunity to generate additional revenue:



Most scenarios provided a positive payback for oversizing the steam turbine:

- 25 years life,
- 9% abatement loss in power generation from steam extraction per previous calculations,

- Availability for 2nd generation plant = 90% versus a typical guarantee availability of 97% for a new build CCGT,
- Note that this is UKising the numbers from the study i.e. basis is 1 x 760 MWe as opposed to 5 x 215 MWe for our plant. (Use as decision tool is OK but the magnitude of the numbers would be different).

In addition, it was decided to oversize the steam turbine generators and their condensers to be able to operate at 100% steam load, but optimised for operation with steam extraction for the CCS. The reasons for the decision were:

- › Mitigation to CCS technology risk
- Allows ~500 MW additional unabated power in case grid is stretched
- > Small additional CAPEX for robust plant design and ~500MW chunky flexibility

Carbon Capture (CC) Plant

The project looked at option of 1 or 2 carbon capture trains per combustion turbine. To meet the Business Drivers of a bankable and reliable solution the project team were interested in an arrangement of 2 x Peterhead or Boundary Dam size as there is existing design acceptance of these plants and Boundary Dam is in operation.

Work done by SNC-Lavalin indicates a significant CAPEX penalty for 2 CC units per Combustion Turbine: a high level estimate calculated an impact £300M per gas turbine train: or £1.3B for 5 trains. The decision is therefore to select 1 x Carbon Capture Train per Gas Turbine. (Noting that the estimate does not account for discount for multiple trains). A Constructability Review has shown that it is feasible to install equipment of the necessary size for 1 x Carbon Capture Train per Gas Turbine.

Cooling

Cooling using Recirculating System (using Wet Cooling Towers) was selected for the plant specification. The following table shows the outcome of evaluation of the cooling options for the project. Whilst direct cooling by river or seawater offers advantages to the project for plant footprint, efficiency, and probably CAPEX, the project team is aware that obtaining extraction permits for large scale water flows is becoming increasingly difficult. Consent risks pose an obstacle to potential plant investment and development: therefore, in order to reduce the risk to the project, this option was not selected.

	Description	CAPEX ¹	Effect on Cycle Efficiency ²	Foot- print ³	Plume	Water Consump- tion	Fan + Pump ³
Dry Cooling Direct Air Cooling	Air is used for condense steam and provide cooling. Cooling at Dry Bulb Temperature of Air.	Highest £142M	-1.4%	57,500 m ²	None	None	14 MW
Hybrid Cooling	Forced Draft Evaporative Cooling with Air Cooling on High Temperature Side. Mixed air flow	Medium £131M	-0.9%	28,400 m ²	Below 0°C	2-3%	23 MW
Recirculating or Indirect Cooling Closed Circuit Cooling System	Natural or Forced Draft Evaporative Cooling. 3-5% of water is consumed as evaporation from the cooling towers and has to be made up. Cooling at Wet Bulb Temperature of Air.	Medium £90M	-0.8%	Medium 21,275 m ²	Visible	3-5%	20 MW
Direct or 'Once Through' Sea Water / River Water Cooling	Used by AMEC Foster Wheeler CCS Benchmark Refresh and by Peterhead CCS. Advantage that there is	Potential Lowest Depends on distance	0%	Assume pump kit roughly same as	None	100%	16 MW

	Description	CAPEX ¹	Effect on Cycle Efficiency ²	Foot- print ³	Plume	Water Consump- tion	Fan + Pump ³
	little extra equipment for the plant to achieve cooling.	to Water		above			
	Cooling at Water Temperature. UK norm = 10°C.						

Notes:

These calculations were performed early in the project and therefore use assumed data as opposed to Basis of Design Data.

- Equipment + Mechanical Erection Labour + Earthworks + Concrete & Civils. Basis of kit, labour, earthworks, and civils is 2016 Power Station Proposal for UK market.
- Calculations run for Siemens SGT5-8000H at 50 Hz. Refer to output files under 181869-0001-T-EM-CAL-AAA-00-00002.
- 3. Figures directly scaled up to 4 CCGT train plant at 2.8 GW nominal.
- 4. Water Cooling temp = 10° C with $\Delta T = 8^{\circ}$ C.
- 5. Air cooling temp = 15°C.
- 6. Load, cost, and layout calculations refer to 181869-0001-T-EM-CAL-AAA-00-00001.

Layout

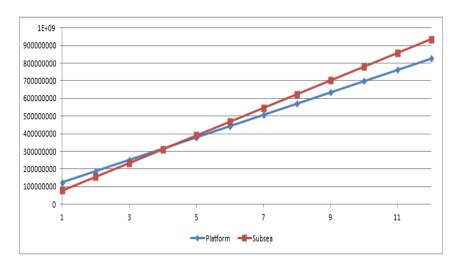
The steam turbine generation (STG) sets could be located near the cooling towers or near their train heat recovery steam generator (HRSG) within the layout of the plant for the plant footprint. The high level consideration for the location was whether to run large diameter cooling water pipe work across the plant from the STG condenser to the cooling towers or whether to run high pressure (HP) steam pipe work across the plant from the HRSG to the cooling tower area. I.e. are low pressure large diameter cooling pipe work runs more cost effective than HP steam pipe work. Due to the thickness of the HP steam pipe work and its higher specification metallurgy it was decided to minimise the HP steam runs and locate the STGs within their trains near their HRSG. This has the advantage of making the trains uniform as opposed to having the STG located outside the

A further advantage of locating the STGs within their trains near their HRSG is to minimise the length of the steam pipe work from the LP extraction on the Steam Turbines to the Amine Strippers.

Subsea versus Platform

Wet wells are usually more expensive to drill and always more expensive to work over but the structure to support wet wells is much cheaper. A comparison of the costs suggests that the tipping point from subsea to platform is around 4 wells. Noting a highest injectivity of around 2.5 Mt/annum + spare there is likely to be a minimum of 5 wells for a 5 train CCGT + CCS scheme: therefore the cost analysis suggests that a platform solution would be more economic.

The graph below shows the total cost versus number of wells for both subsea and platform solutions:



A dry well platform solution would also be a risk mitigation measure until offshore CO_2 injection wells are better understood because platform allows greater monitoring and intervention, and lower cost intervention, if there are issues with the injection wells.

- If a permanent gas heater is to be installed, a platform and dry wells is the only option.
- > Drywells tend to have a higher operational reliability than subsea wells;
- There is a lower project risk drilling through a wellhead platform in the North Sea as the operation is less weather dependent than a drilling subsea wells.
- As these will be the first CO₂ injection wells in the North / Irish Sea the improved accessibility to the wells would be prudent until some operating experience has been obtained.
- If a permanent wash water package is to be installed, a platform and dry wells is the only option.
- › Better flexibility for future expansion.

Substructure Type

The main advantages and disadvantages to be achieved from using three or four legged jackets are identified as, but not limited to, the following:

Key Area	Three Legs	Four Legs
Redundancy	Tripod structures have a reduced redundancy capacity in the event of a single leg being rendered in-effective. Therefore there is an increased risk of structural failure in the event, for example, of a ship impact.	Traditional four legged jackets have increased redundancy over tripod jackets due to the additional leg. When correctly designed, the four legged jacket should at least allow repairs to take place, if not continuous operation.
Section Size	Sections sizes, in general, will be larger than four legged jackets due increased loading per leg.	Section sizes, in general, will be smaller than three legged jackets due the load being distributed over a greater number of legs.
Material	Overall, the amount of materials will be less than a four legged jacket.	A four legged jacket will require a greater amount of material.
Foundations	Mudmat foundations and piles will require a greater capacity as there will be approximately 33% more load per leg compared with a four legged jacket. This will add additional weight, and require lengthier or more complicated installation procedure.	Foundations will generally be smaller and lighter than on a tripod, as the axial and shear load per foundation is reduced. The number of piles will likely be the same or greater, however the weight per pile should be less.
Total Jacket Weight	2,836 Te	2,996 Te
Percentage Weight Increase	0%	+5.6%
Estimated Fabrication Cost Differential	0	£1,280,000

In general, a three jacket used for the injection of Carbon Dioxide (CO_2) into a CO_2 store using either depleted reservoirs or saline aquifers in a North Sea environment will be around 5% (160Te and £1,280,000 less) lighter and cheaper compared with a four legged jacket. However, four leg jackets offer a basic level of redundancy in the event of accidental loading (e.g. ship impact, etc), that three legged jackets do not. In addition, the foundations of a three legged jacket will be required to be more substantial and withstand greater bearing and shearing forces, than on a four legged jacket and hence the installation cost per pile may be greater given an increased weight, diameter and drive depth.

Plant Description

The Plant Description can be found in the attached Technical Note - Plant by Plant Description, document reference 181869-0001-T-EM-TNT-AAA-00-00002.

Roll Out Trajectory

The Roll Out Trajectory can be found in the attached Technical Note – Roll Out Trajectory, document reference 181869-0001-T-EM-TNT-AAA-00-00003.

Project Design Basis

The Project Design Basis, document reference 181869-0001-T-EM-DBS-AAA-00-00001, is attached to this document.

Contracting Basis

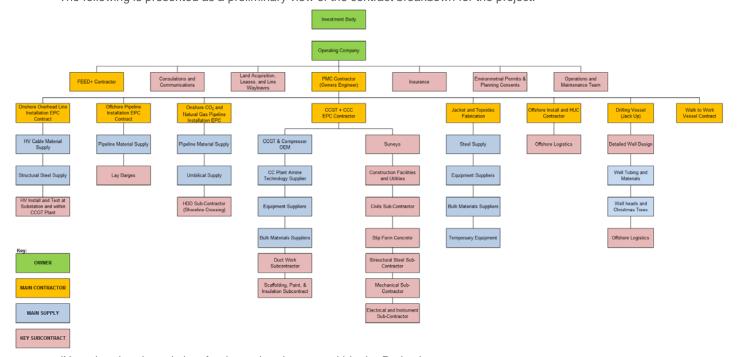
Contract Strategies

There are a range of contract strategies that can be designed in order to maximise the probability of successful project delivery. The selected contract strategy needs to be aligned with the project scope, technology, and complexity. The selected contract strategy also needs to be aligned with the competence, knowledge, and capability of the Project Owner (for example, a major oil international oil company will have a wide range of project management, project controls, engineering, technology, and commissioning competences, knowledge, and capability that would not be found within an investment bank).

It is assumed that the project delivery would be split into a number of EPC contracts: this is because contractors generally do not possess the range of competence and capability to execute all areas of the project. Also, the project becomes more controllable by splitting the delivery into a number of more manageable contracts.

The lower the level of contracting selected by the Project Owner, the more control the Project Owner will have over the execution of the project: however, the lower the level of contract selected the larger the team the Project Owner needs to employ. Typically Project Owners want to contract at Tier 1 level: true Tier 1 level is where the EPC Contractor has direct control of works and is only subcontracting the majority of works down 1 level or directly performing. If the EPC Contractor is sub-contracting sub-contracts then control is quickly lost between the project owner and a sub-sub-subcontract layer. In such cases, the arrangement suggests that the contracting is set at too high a level and the Contracts need to be broken down.

The following is presented as a preliminary view of the contract breakdown for the project:



(Note that the above is just for the major elements within the Project).

Risk

There is however a balance is risk between the level of contracting and the size of contracts. Some organisations are happy to pass on all risks to their EPC Contractors, even if they lose some of the control because the EPC Contractor passes down scope to many different levels of sub-contract. There is a recent trend to some major energy companies controlling more work themselves (e.g. separate early works, site enablement, and ground works as these are seldom self-performed by EPC Contractors but usually sub-contracted to local Civils contractors).

Major Contracts

The following is a brief summary of each of the major Contracts

- Onshore CCGT and CCC Plant: Power Generation and Carbon Capture plant located within the plot boundary as described in Plant Footprint, document reference 181869-0001-D-EM-LAY-AAA-00-00001-01. This contract would also include the shoreline CO₂ pressure booster station (if required) because the skill set of this contractor is more aligned to the pump or compression station than a linear asset pipeline installer. A common Contractor for both main plant and pressure booster station would ensure commonality of specification, models, spares, etc., for ease of operation and maintenance;
- Onshore pipelines and shore crossing: installation of the new natural gas pipeline connecting the onshore plant to the National Transmission System. Installation of the new CO₂ pipeline to connect the plant to the shore crossing. Scope will include the shore crossing and any Above Ground Isolation Valve Stations;
- > HV Overhead Line connecting the power plant to the national grid. The contract will include HV installation and connections within the Power Plant and at the connection point to the national grid (either mods to existing substation or installation of a new substation);
- Landfall and Subsea Pipeline: Landfall, of the new offshore CO₂ pipeline to connect to the offshore Well Head Platform (WHP). Subsea pipeline lay will include installation of the Sub Sea Isolation Valve (SSIV) close to the platform, tie-in spools, installation of a new control and power umbilical, and a new Topside Umbilical Termination Unit (TUTU);
- Fabrication of platform, jacket, and piles; this would be fabrication in a vard and would include procurement and installation of equipment on the topsides, and pre-commissioning works on topsides to minimise offshore works. Scope of works would end at load out.
- Installation of platform, jacket, and piles in the offshore installation. Contract would include offshore hook up and commissioning. Some contractors may be able to combine with installation of subsea pipeline. Some contractors may be able to combine with fabrication of jacket and topsides.
- > **Drilling:** drilling of CO₂ injection wells using a jack up and a cantilevered drilling rig to drill wells through the Well Head Platform.
- Walk to Work Vessel: Provision of walk to work (W2W) vessel. This could be a dedicated vessel for the CO₂ Injection Platform, or provision of Walk to Work Vessel services as part of a wider fleet serving other facilities. A W2W vessel would be required for the offshore hook up and commissioning services as a flotel would be too large and costly for the required scope.

Contract Basis

It is assumed that the main contracts for the whole CCS chain would be competitive tendered on the following

- > Robust FEED study provided to EPC Contractor by Project Owner
- > Engineer, Procure and Construct (EPC) contracting model
- > Fixed price lump sum turnkey
- Each of the EPC Contracts will be placed and managed by an Implementation Manager employed directly by the Project
- > PMC and Owner's Engineer services will support the Implementation Managers (assumption that Project Owner would not have sufficient staff to provide this)

The Project Management Contractor (PMC) would operate in support of the Implementation Managers and provide:

- Office support services:
- Project administration;
- Quality assurance;
- Design and construction safety management;
- Owner's Engineering,

Technical authority in support of technical decisions Technical studies where required to evaluate options and alternatives Response to technical queries from EPC Contractors

Design reviews and Design Audits to ensure design integrity and design sufficient to meet EPC Contract specification

Review of engineering deliverables

› Project services,

Project reporting,

Monitoring progress against plan with early identification of problems Information management,

Risk management, and

Interface management;

> Supervision and personnel that may be necessary to manage and control the execution of their works.

General Requirements

The General Requirements included below are taken from SNC-Lavalin's Request for Proposal terms and conditions for the Peterhead project. These are intended to replicate the General Requirements for the EPC Contractor to be used in the development of the WP3 cost model. The General Requirements set out the items which will be covered in the cost estimating in WP3. This work will be further developed in the Basis of Estimate.

The EPC CONTRACTOR shall perform and complete the EPC CONTRACT WORK in accordance with the EPC CONTRACT. The EPC CONTRACTOR represents and warrants that, when completed, the PERMANENT EPC CONTRACT WORK shall meet all requirements ensuing from the EPC CONTRACT.

The EPC CONTRACT WORK shall include detailed engineering and design, procurement, fabrication, construction, commissioning assistance, construction management, project management, supervision, testing, defects correction, provision of MATERIALS and CONSTRUCTION EQUIPMENT, and all other necessary services, personnel and labour.

The EPC CONTRACTOR shall take full responsibility for the adequacy, stability and safety of all operations and methods necessary for the performance of the SUBCONTRACT WORK.

The EPC CONTRACTOR shall provide all tools, equipment, systems, software, hardware, MATERIALS and CONSTRUCTION EQUIPMENT and all other things, necessary to efficiently and timely perform the EPC CONTRACT WORK and complete the PERMANENT SUBCONTRACT WORK; and shall carry out all of its obligations under the SUBCONTRACT and shall execute the SUBCONTRACT WORK (i) in accordance with APPLICABLE LAWS, (ii) with all due care and diligence, and (iii) in accordance with sound industry standards, principles and practices, which are recognized and generally accepted in the international oil, gas and petrochemical industry as appropriate for use in the design, engineering, procurement, construction and commissioning of facilities similar to the PERMANENT WORK.

The processes selected by the EPC CONTRACTOR, methods of production and technology and all services incorporated into the EPC CONTRACT WORK or provided for the purposes of the EPC CONTRACT WORK, shall meet sound standards, principles and practices which are recognized and generally accepted in the international power industry, including standards of efficiency, reliability, health, safety and environmental management. (i.e. power industry pricing not Oil & Gas Industry).

All MATERIALS provided by the EPC CONTRACTOR shall, when installed be new and unused, of good quality and workmanship

The EPC CONTRACTOR shall obtain all import licences for either temporary or permanent importation of CONSTRUCTION EQUIPMENT and shall comply with importation procedures designated by the relevant AUTHORITIES for the importation of CONSTRUCTION EQUIPMENT.

At all WORKSITES, the EPC CONTRACTOR shall supply and provide at his own cost and risk secure laydown areas and storage for any CONSTRUCTION EQUIPMENT and MATERIALS, required to perform the EPC CONTRACT WORK.

Before departure from any WORKSITE, the EPC CONTRACTOR shall clean it and leave it free from all MATERIALS, CONSTRUCTION EQUIPMENT, SURPLUS MATERIALS, and all debris and waste. Disposal of waste and debris shall be undertaken in a legal and safe manner and in compliance with relevant APPLICABLE LAWS. "Waste" includes any unusable or unwanted materials or substances irrespective of whether they have any value.

The EPC CONTRACTOR shall obtain without delay and maintain, comply with and where required, implement in accordance with their terms, during the performance of the EPC CONTRACT WORK all permits, licenses, approvals and other consents as are necessary for the EPC CONTRACTOR and its SUB-CONTRACTORS to perform the EPC CONTRACT WORK.

Project Scope of Supply

The Project Scope of Supply is as defined in the attached documents:

- Basis of Design, document reference 181869-0001-T-EM-DBS-AAA-00-00001.
- Block Flow Diagram Outline Scheme Design at Plant Level, document reference 181869-0001-D-EM-BLK-AAA-00-00001-01.
- > Technical Note Plant by Plant Description, document reference 181869-0001-T-EM-TNT-AAA-00-00002.
- Block Flow Diagram Outline Scheme Design at Unit Level, document reference 181869-0001-D-EM-BLK-AAA-00-00002-01.

The scope of each EPC contract includes:

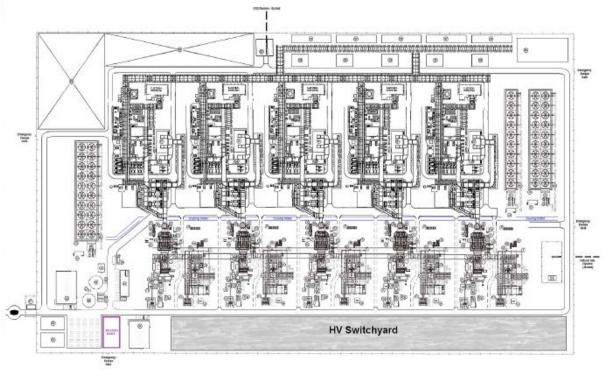
- › Project Management,
- > Project Controls,
- > Detailed engineering,
- > Procurement and Fabrication elements,
- Material supply within the boundary limits,
- › Construction,
- > Subcontracts,
-) HSSE,
- › Quality Assurance and Quality Control,
- > Commissioning and Start-Up,
- › Performance Testing and Handover,
- Cost of risk,
- › Contingency for scope and contract type,
- › EPC Contractor's overhead and profit.

Plant Footprint

A plant footprint of 50 Hectares has been allocated for the Site Selection. 40 Hectares of the allocation is for the Site Layout with an additional 10 Hectares for Construction Camp and Laydown.

Plant Area	Layout (Ha)
Power Generation	8.4
Carbon Capture and Compression	18.6
Cooling Towers	2.3
Water Treatment Plant	2.7
Utilities and Facilities	3.0
Roadways, etc	2.0
HV Switchyard	3.0
Total Plant Footprint	40.0
Construction Camp / Laydown Outside of Boundary	10.0
Total Area Required	50.0

The following shows a potential layout for the Thermal Plant with CCS using 5 trains.



Please refer to the attached Plant Footprint Drawing and Attachment 1 for further details on the Plant Footprint, document reference 181869-0001-D-EM-LAY-AAA-00-00001-01.

Plant Termination Points

Onshore Plant

The following plant termination points have been identified:

- › Natural Gas (Pipeline)
- > HV Electrical Power Export (OHL) back feed for Black Start
- › Potable Water (Pipeline)
- Raw Water Cooling Circuit Make-Up (Pipeline or conduit)
- > Sewage (Pipeline)
- > Waste Water (Pipeline or Conduit) following treatment plant
- > Telecomms (Fibre)
- CO₂ Export (Pipeline)
- > Tanker loading / unloading (Chemicals / Wastes)
- Solvent handling
- → Bottles (Speciality Gases N₂, H₂)

Offshore Plant

The following plant termination points have been identified:

- > Electrical Power Supply (J-Tube)
- > Seawater (Caisson)
- > Treated Water Discharge (Caisson)
- Control (J-Tube)
- > Telecomms (Radio / Microwave)
- CO₂ Supply (Riser)

Summary of Key Decisions

The following are the key decisions made in the development of the specification for the Thermal Power with CCS: Generic Business Case.

Overall Scheme

The plant configuration has been decided as trains, with each train being built up of the following components: Combustion Turbine - Nominal capacity 500MW; Heat Recovery Steam Generator (HSRG); Steam Turbine (ST) - Nominal capacity 200 MW;
› Heat Recovery Steam Generator (HSRG);
› Steam Turbine (ST) - Nominal capacity 200 MW;
 Flue gas treatment, with Selective Catalytic Reduction (SCR), for NOx removal;
Carbon Capture (CC) Unit, i.e., there will be one CC Unit for each CCGT train;
CO ₂ Compressor with dehydration.
A 5 train plant footprint would be 40Ha.
Allowing 10Ha for offsite Construction Camp and Laydown a total area of 50Ha is required for the site selection work.
The plant footprint has been divided into zones allowing the Power Plant to be constructed and commissioned without the CCS operational.
 A number of decisions were made with regards to the layout of the plant: these can be found in the "Approach to Layout" section of the Notes to Accompany the Plant Footprint, document 181869-0001-D-EM-LAY-AAA-00-00001-10 Attachment 1: Turbines located upwind of plant so contaminants are not ingested in air intake Steam turbines located adjacent to HRSGs to minimise length of HP steam pipe work Cooling Towers located cross wind from remainder of plant – down wind would have been preferred to prevent drift corroding plant – however, this would have made the cooling runs too long. High pressure CO₂ located opposite end of plant from manned area to reduce exposure to operating and maintenance personnel to risk of a major leak. Natural Gas located opposite side of plant from manned area to reduce exposure of personnel to risk of explosion.
A plant configuration of 5 trains has been agreed with the ETI. This most closely matches the 3GW and 10 MTPA sizing criteria for the plant.
The plant will be built in full as opposed to deploying 1 CC train with initial built.
Providing 1 CC Train in order to debug before deploying remaining 4 trains would not meet the ETI's objective of deploying large scale CCS and would not meet the bankable criteria as it would indicate that the CC Technology is not proven. Should investment banks make their own judgement on technology reliability and deem it unreliable enough to merit staged construction then the layout of the compression and dehydration area may have to be redesigned to provide individual substations per train to allow 1 CC Train to be commissioned before the remainder are built.

Power Plant

1 OWOI I Idill	
OEM Selection	Decided that to control CAPEX (to keep scheme competitive) the scheme would be open to the machines from the main OEMs for CCGT technology of class H and class J turbines: GE, Siemens, and MHI.
	Ansaldo GT26 not considered as is too small. Ansaldo GT36 is still in development – not viewed as a bankable solution.

CCGT Sizing	The Scheme design will be based on a nominal gas turbine size of 500 MW and 62% LHV efficiency. It is understood that machine sizes and efficiencies from the OEMs are higher / lower than this figure. However, a scheme which is open for any major OEM machine would allow competition between the OEMs offering best value for a potential investor. Where specific calculations are to be undertaken SNC-Lavalin would tend towards GE as this is our recent class-H data. Future developments in turbine technology could tend to increase efficiency of combined cycle to 64% - 65% (LHV) using steam cooling and reheat, however this is a future generation of turbine. (Gulen, 2014)
Emissions Controls	Emissions controls are required as need to be able to run the CCGT without CC Plant. NOx control is required anyway to protect amine and to ensure safety. The design needs to ensure NOx control is located before gas turbine exhaust stack.
CCGT Configuration	A multi shaft arrangement for the CCGT has been selected.
Steam Supply	Steam supply through steam extraction from the Steam Turbine has been selected over duct firing, separate CHP plant, steam let down from interstage IP/LP, or an auxiliary boiler. The ETI's prior work has shown duct firing and external boilers to be less efficient. Also, it is common experience that duct firing would not meet the reliability Business Driver agreed with the ETI. A separate CHP plant does not meet the train concept for the project. Steam let down from interstage IP/LP is not the most efficient use of energy. Note that the project is for a new build CCGT with CCS, not a conversion of
O : 0: T !:	existing CCGT to CCS, or a Carbon Capture Ready (CCR) design.
Oversize Steam Turbine	Oversize the steam turbine and condenser in order to be able to operate near to a best in class CCGT should CCS not be in operation.
Variation of Natural Gas LHV on Gas Turbines	There is no clear relationship between fuel lower heating value (LHV) and power output of gas turbines. This has been demonstrated by modelling work and confirmed by an OEM.

Carbon Capture & Compression Plant

Selection of Amine Post Combustion Capture	Amine Post Combustion Capture has been selected for the project as this process has already been utilised for Carbon Capture, and is based on a mature technology.
Acid Wash	Peterhead uses a proprietary amine solvent to capture CO ₂ from Gas Turbine (GT) exhaust flue gases. Cansolv (process licensors) proposed an Acid wash system for Peterhead. We believe that this was included in the design due to the presence of nitrous oxides (NOx) in the flue gas to the Carbon capture (CC) plant capture; amines (particularly tertiary amines), when exposed to nitrous oxides, may form nitrosamines which are known to be carcinogenic.
	The acid wash is currently retained but will be reviewed with Cansolv in WP3.
Gas Gas Heater (GGH)	The Peterhead design had a GGH to reheat the CO ₂ abated flue gases from the absorber, in order to minimize plume formation. Although the power plant flue gases lose some of their heat in the GGH, the heat transfer is poor, and the main cooling is done with cooling water in the Direct Contact Cooler (DCC).
	Consents require no visible plume – therefore the GGH is required.
Compression	Selection of 1 x Carbon Capture train per Gas Turbine with the compression sizing being approx: 20 MW. This is lower CAPEX than multiple compressors per train and there are sufficient references for this size of CO ₂ compressor.
Oxygen Removal	Should assume that high pressure CO ₂ should be classified as "dangerous fluids" for the purpose of the Pipelines Safety Regulations 1996 and "dangerous substances" for the purpose of COMAH 1999 in the export quantities from a pipeline. Therefore, ALARP principals should be applied. The material selection of the pipeline, considering the corrosion rate, should ensure that risk of corrosion failure, and therefore large release of CO ₂ , is ALARP.
	Cansolv H&MB showed no O_2 in the product CO_2 leaving the stripper which could have motivated Peterhead to remove the O_2 reactor.
	Remove O_2 Removal – the Generic Business Case plant scheme is very similar to Peterhead's.

Transport

Line Sizing	Initial estimate for CO ₂ pipeline sizing is 24" however, this requires very high pressure CO ₂ (200 barg). Sizing the pipeline over 24" requires special pipeline material as the required thickness would exceed standard material schedules.
	Pipeline size (& cost) will need to be reviewed in WP3 against compression size (& cost) to indentify the most cost effective solution based on the locations selected in WP2, the size of plant allowed by the site selections, and the resultant length of pipeline.

Offshore Storage

Subsea versus Platform	For the number of wells selected a dry well (platform) solution appears to be lower cost. A platform solution also presents a risk mitigation measure for offshore CO ₂ wells as it easier and lower cost to monitor and work over wells from a platform.
Platform Substructure	In general, a three legged jacket used for the injection of Carbon Dioxide (CO_2) into a CO_2 store using either depleted reservoirs or saline aquifers in a North Sea environment will be around 5% (160Te and £1,280,000 less) lighter and cheaper compared with a four legged jacket. However, four leg jackets offer a basic level of redundancy in the event of accidental loading (e.g. ship impact, etc), that three legged jackets do not. In addition, the foundations of a three legged jacket will be required to be more substantial and withstand greater bearing and shearing forces, than on a four legged jacket and hence the installation cost per pile may be greater given an increased weight, diameter and drive depth.

Abbreviations

The following abbreviations have been used in this document:

Abbreviation	Description
ALARP	As Low as Reasonably Practicable
ATEX	Explosive Atmosphere
CAPEX	Capital Expenditure
CC	Carbon Capture
CCC	Carbon Capture and Compression
CCGT	Combined Cycle Gas Turbine
CCS	Carbon Capture and Storage
CfD	Contract for Difference
CO ₂	Carbon Dioxide
CSR	Comprehensive Spending Review
DECC	Department of Energy and Climate Change, (as succeeded by the Department of Business, Energy and Industrial Strategy in July 2016).
EPC	Engineering, Procurement, and Construction
ETI	Energy Technologies Institute
GT	Gas Turbine
HP	High Pressure
HRSG	Heat Recovery Steam Generator
HSSE	Health, Safety, Security, and Environment
HV	High Voltage
LLP	Limited Liability Partnership
LP	Low Pressure
OHL	Overhead Line
OPEX	Operating Expenditure
P10/P50/P90	The point on the probability distribution for estimated costs at which there is a 90% / 50% / 10% probability that costs will not exceed this value
PMC	Project Management Contractor
RfP	Request for Proposal
SCR	Selective Catalytic Reduction
SSIV	Subsea Isolation Valve
ST	Steam Turbine
STG	Steam Turbine Generator

Abbreviation	Description
TPwCCS	Thermal Power with Carbon Capture and Storage
TUTU	Topsides Umbilical Termination Unit
UK	United Kingdom
UoS	University of Sheffield
USA	United States of America
W2W	Walk to Work
WHP	Wellhead Platform
WP	Work Package

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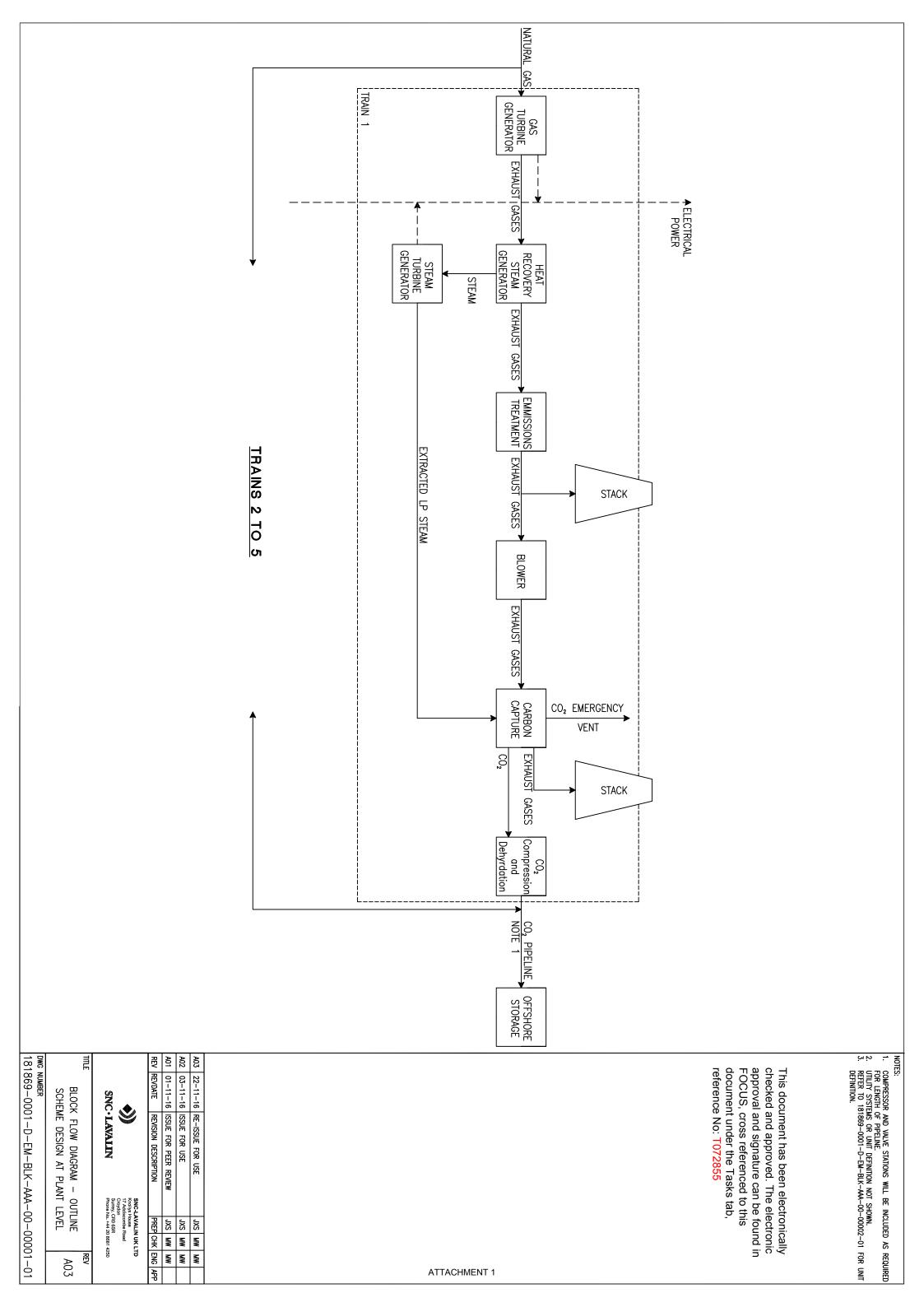
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Block Flow Diagram

181869-0001-D-EM-BLK-AAA-00-00001-01



Overall Scheme Options Chart

181869-0001-D-EM-DIA-AAA-00-00001-01



SNC · LAVALIN

Project Number 181869
Project Name Thermal Plant with CCS: Generic Business Case

Project Location England

Document Number Document Revision 181869-0001-D-EM-DIA-AAA-00-00001-01

11-Nov-16

Option	Inlet to Plant	Gas Turbines	Steam Turbines	HRSG	Cooling	Flue Gas Treat	CO ₂ Capture	Compression	CO ₂ Pipeline	ESD	Shoreline	CO ₂ Pipeline	Offshore
1			Single Shaft		Air Cooled	SCR for Nox			Dense Phase	Valve Station	Pipeline	Subsea Pipeline	
2			Multi Shaft		Cooling Tower				Liquid Phase		Compression Station		
3			Multi Shaft		Direct Cooling						Pumping Station		
Size	= 1 x nom 36" For whole plant	= 2 x nom 500 MW	= 2 x nom 200 MW = 1 x nom 400 MW	Stack before HRSG Stack after HRSG			= 2 x nom 229 t/hr = 3 x nom 152 t/hr = 4 x nom 114 t/hr	= 1 x nom 42 MW = 2 x nom 21 MW = 3 x nom 14 MW	= 1 x nom 60" For whole plant	= 1 every 10 to 20 km			= 1 offshore platform = injection wells
Applicable Ir White Rose Peterhead AMEC FW Re Boundary Da	port												
Notes 1	. Natural Gas Delivery Pipeline complete with Metering and Gas Superheat into turbines	Large, high effiency Class H / J Turbines per proposal.	Extraction Steam Turbine assumed: low grade steam is required for the CCS plant.	Stack before HRSG allows for bypass of Steam System altogether.	Cooling Tower includes sub-option for Hybrid.		Peterhead was a 1 x 145.5 t/hr	Peterhead was 1 x 15 MW: 1.13 bara to 124 bara	Dense phase pipeline - onshore and offshore Alternative is liquid phase if worried about lower temperatures.	Every 10 to 20 km based on section 3.8 of "CO ₂ pipeline infrastructure" produced for IEA Environmental Projects Limited	Depends on the pressure drop in pipelines as to whether additional pump / compressor station required.		Number of wells estimated from Peterhead and White Rose. Will be dependent on injectivity.
2	. Approx 572 mmscfd to feed 6 turbines	2 x 2 for 2 GW plant and 3 x 2 for 3 GW plant.	2+1 is lowest CAPEX, but has lower reliability. 1+1 single shaft next lowest CAPEX, followed by 1+1 multishaft.				Includes Amine Absorbtion and Amine Stripping and Exhaust Stack	Includes dehydration, O2 removal, and metering	Size will depend on pressure drop, etc		Dense phase = compressor. Liquid phase = pump		Whether is new or existing facility is site specific
3		Includes Heat Recovery Steam Generator (HRSG) on Exhaust	Single shaft is lower CAPEX (1 less generator, less aux, lower kW parasitic), smaller footprint. However, less flexible.				Do we need different numbers of Absorbers and Strippers?	Alternative for a combination	Dry CO ₂ allowing selection of Carbon Steel				
4		Is exhaust gas recycle included?	Bouchaine is Single Shaft.						Larger line would be required if becomes trunk line for future projects				

Plant by Plant Description

181869-0001-T-EM-TNT-AAA-00-00002



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00-00002

TECHNICAL NOTE

From: Matt Wills Date: 21-Dec-2016

Project: Thermal Plant with CCS: Generic Business Project No.: 181869

Case

The ETI

Subject: Plant by Plant Description

Distribution: AECOM

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Contents

- Introduction
- Power Generation Plant
- Carbon Capture and Compression Plant
- Plant Utilities
- Transportation
- Offshore Storage

Introduction

A high level process scheme has been agreed with the ETI at a meeting on Thursday 27th October.

This document is a high level description of each of the major components of the process scheme.





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The high level process scheme can be seen in document Block Flow Diagram - Outline Scheme Design at Plant Level, number 181869-0001-D-EM-BLK-AAA-00-00001-01.

This document is provisional – additional detail will be added for the final report following the design work undertaken in Work Package 3.

Function

Scheme Area	Purpose
Power Generation Plant	The power generation plant generates electrical power by burning natural gas in a gas turbine. Waste heat from the gas turbine exhaust is used to generate steam which is used to generate further electrical power using a steam turbine.
	The electrical power is exported to the UK National Grid from where is serves the needs of industry, commerce, and domestic homes.
Carbon Capture & Compression Plant	The carbon capture plant uses Amine to separate carbon dioxide (CO ₂) from the exhaust combustion gases produced by burning natural gas in the gas turbine.
	The CO ₂ is then compressed and dried ready to be transported for storage.
Plant Utilities	The plant utilities provide the sub-systems required to run the power generation and carbon capture, such as compressed air, nitrogen, and water.
Transportation	CO ₂ is transferred by pipeline from the carbon capture plant to the offshore store. If the onshore pipeline is a of extended length then block valve stations will be required in order to safely isolation sections of the pipeline. A booster station may also be required in order to boost the pressure of the CO ₂ before sending offshore.
Offshore Storage	CO ₂ is stored in an underground saline aquifer deep under the seabed. Injection wells will be drilled to allow the CO ₂ to flow into the underground store. The wellheads will either be located on the seabed or will be installed on an offshore platform.



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Power Plant

The CCGT will be a 1 x 1 configuration combined cycle plant such that each train comprises of:

- 1 Gas Turbine Generator (GTG) with a nominal output of 500 MW
- 1 Heat Recovery Steam Generator (HRSG)
- 1 Steam Turbine Generator (STG) with a nominal output of 200 MW

The exhaust gas from each GTG will be directed to the associated (HRSG) where energy is recovered from the exhaust to generate high-, intermediate-, and low-pressure (HP, IP, and LP respectively) steam.

The Steam Turbine Generator will be a two-casing, combined HP/IP section, double-flow LP section, triple pressure with reheat. (Reheat will be provided by the Combustion Turbine exhaust gases in the HRSG). Exhaust steam from the STG will exhaust into a shell and tube condenser using a wet mechanical draft cooling tower for cooling water.

Auxiliary cooling will be provided with a plate and frame heat exchanger with the glycol loop on the plant side and cooling tower water on the other side.

The steam piping system delivers steam from the HRSG to the STG where it is used to produce additional power. In addition, exhaust steam from the high-pressure section of the steam turbine is directed back to the HRSG to be mixed with IP steam, re-heated, and returned to the STG.

A steam bypass system will be provided to bypass steam to the hybrid cooling system and enable the combustion turbine generator to operate when the steam turbine generator is out of service, at start-up or shut down mode.

Uncontrolled LP Steam extraction will provide LP steam to the Carbon Capture (CC) Plant. The STG and its condenser will be sized for the full steam flow from the HRSG such that the CCGT can produce full power when the CC Plant is not in operation. The turbine performance will be optimized for operation with extraction.

Energy will be generated from the 3 turbine generators at 20 kV, and the electrical terminal point is the HV dead end structure.

For this study a GE 9HA.02 CCGT and a GE D600 steam turbine are considered. The gas turbines will fire only natural gas.

The power plant consists of:

- One (1) combustion turbine generator (CTG) set with evaporator air inlet cooling.
- One (1) three pressure, three drum heat recovery steam generator with reheat (HRSG)
- One (1) condensing, reheat steam turbine generator (STG)
- STG exhaust steam condensing and auxiliary cooling: STG steam exhausting to a shell & tube condenser using a wet mechanical draft cooling tower for cooling water.
- Condensate and Feedwater Systems



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- Auxiliary Steam System
- STG steam by-pass system
- Natural Fuel system for each CTG
- Continuous Emissions Monitoring System (CEMS) for the HRSG stacks

The combustion turbine will be outdoors with outdoor enclosures. The STG will be indoors. The HRSG will be outdoors, and have three pressure levels with reheat, furnished with a selective catalytic reduction (SCR) system for the control of NOx emissions, and an oxidation catalyst for the control of CO and VOC emissions. The SCR will use aqueous ammonia as the reagent.

The equipment and systems will be capable of operating continuously at all load conditions between minimum emissions compliance and peak operation. Operating conditions are expected to vary seasonally with periods of cycle operation including base load, minimum load, cold, warm, and hot starts.



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TECHNICAL NOTE

Carbon Capture and Compression (CCC) Plant

The following section is developed from Peterhead document "Basic Design and Engineering Package, Document Number PCCS-00-PTD-AA-7704-00002 revision K05.

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Pre-Treatment

The gas pre-treatment system comprises the following major components:

- Booster fan
- Direct Contact Cooler (DCC)
- Gas-Gas Heat Exchanger

The flue gas transferred to the CC Plant is taken from the outlet duct of the Heat Recovery Steam Generator (HRSG). A booster fan provides sufficient pressure to drive the flue gas through the Carbon Capture Plant to the stack.

A damper arrangement or a Variable Frequency Drive (VFD will control the booster fan).

Flue gas from the booster fan flows to the Gas-Gas Heat Exchanger where it is cooled to 70°C, whilst heating the treated flue gas from 30 to 75°C. A rotary regenerative heat exchanger is proposed (similar to the type applied in power stations to preheat boiler air) in which a slowly rotating element transfers heat from the hot side to the cold side. A purge and scavenge fan is used to maintain a low level of leakage between the two sides.

The flue gas then flows into the DCC, where it is further cooled to 30° C by direct contact with recirculating water. It is critical to saturate and cool the flue gas prior to feed to the CO_2 Absorber Tower to ensure proper CO_2 absorption and prevent excessive water evaporation from the amine solution in the CO_2 absorber tower.

CO2 Capture System

The CO₂ Capture System comprises the following major components:

- CO₂ absorption section;
- Water wash section:
- Acid wash section;
- CO₂ stripper;
- Amine filtering (if required for CCGT unit);
- Ion Exchange Unit (IX); and
- Thermal Reclaiming Unit (TRU).

Consideration needs to be given whether the IX and the TRU can be shared on a larger plant.

CO₂ Absorption

On exiting the pre-treatment system, the pre-treated flue gas is ducted to the CO₂ absorber. CO₂ absorption from the flue gas occurs by counter-current contact with absorbent solvent in a vertical multi-level packed-bed lined concrete CO₂ absorber tower.

The flue gas entering the absorption section of the tower will have sufficient pressure to overcome the pressure drop in the tower packing and flue gas re-heater before being discharged to atmosphere as lean



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flue gas: an ID fan on the cold flue gas leaving the tower should be considered as the flue gas is being brought back down to grade for the GGH.

The Absorber Feed Pumps deliver CO₂ lean amine from the Lean Amine Tank through the Lean Amine Cooler to the top of the CO₂ absorption section. The lean amine is cooled in Lean Amine Cooler to prevent water loss from evaporation into the flue gas, to maintain an overall water balance in the absorbent DC inventory and to maximise capture efficiency.

The treated flue gas leaving the top of the CO₂ absorption section will pass through a water wash section and acid wash section before being released through the stack to the atmosphere.

Water Wash Section

A water wash packed bed section is included at the top of the CO₂ absorber to capture volatile or entrained amine mist and to condense water from flue gas to maintain the water balance in the system. Wash water is drawn from a chimney tray and is re-circulated to the top of the packed section, via the Water Wash Cooler, by the Water Wash Pumps. The water wash cooler reduces the temperature of circulating wash water, which minimises water loss and enhances capture efficiency of the volatile amine. Water condensed from the flue gas into the wash water section overflows from the chimney tray down into the absorber sump. The treated flue gas leaving the water wash section flows upwards to acid wash section.

Acid Wash Section

An acid wash packed bed section is included above the water wash section to capture mainly light amine components but also other entrained amine containing mist and potentially evaporated amine from the water wash section to minimise the emission level to the stack. The acid wash pH is maintained at 3 to maximise the light amine components capture. An acid and water mixture is drawn from a chimney tray at approximately 30°C and 1.033 bara is re-circulated to the top of the packed section, by the Acid Wash Pumps at 30°C and 1.028 bara. Captured amine and other volatile components will be converted into salts by the sulphuric acid, which will suppress the vapour pressure and minimise the emission of amine to the environment. The amine salt will be purged by a take-off from the chimney tray located at the base of the acid wash section of the absorber and routed to the waste water treatment system. The flue gas leaving the acid wash will be reheated to approximately 70°C preventing plume formation and enhancing dispersion of light amine components and other amine degradation product emissions, before being released to atmosphere. The vent from the vacuum package of the Thermal Reclaimer Unit (TRU) will also contain light amine components; therefore it is routed to the acid wash section so that any amine degradation products generated can be captured.

CO₂ Stripper

The rich amine is collected in the bottom sump of the CO₂ absorber at 35°C and 1.063 bara and is pumped by the Rich Amine Pumps to 9.52 bara and heated in the Lean/Rich Exchangers to approximately 114°C recovering heat from the hot lean amine discharged from the CO₂ Stripper. Rich amine exiting the lean/rich exchangers is piped to the CO₂ stripper for amine regeneration and CO₂ recovery.

The rich amine enters the column under the CO₂ reflux rectification section and flows onto a gallery tray that allows for disengagement of vapour from the rich amine before flowing down to the two stripping packing sections via the trough type liquid distributor.

The rich amine is stripped of CO₂ by LP steam at approximately 140°C and 3 bara in the CO₂ Stripper Reboilers flowing in an upward direction counter-current to the rich amine.

Lean amine flowing to the bottom packing section of the CO₂ stripper is collected on a chimney tray and gravity fed to the reboilers. A mixture of water vapour and lean amine flows from the reboilers back to the



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stripper sump, underneath the chimney tray. Water vapour flows upwards through the chimney tray to strip the CO₂ while the lean amine collects in the bottom sump.

The Lean Amine Pump delivers the lean amine from the CO₂ stripper sump at 2 bara to the lean amine tank at 2.75 bara after being cooled in the lean/rich amine heat exchangers to 40°C.

Water vapour in the stripper, carrying the stripped CO₂, flows up the stripper column into the rectification packing section at the top, where a portion of the vapour is condensed by recycled reflux at 25°C and 1.95 bara to enrich the overhead CO₂ gas stream.

Excess water with amines that may accumulate in the amine loop is bled off as stripper reflux to the Effluent Treatment Package.

A mist eliminator is installed below the rectification section of the stripper to minimise water droplets and amine entrainment with the CO₂ rich gas.

The rectification section contains three bubble-cap trays instead of packing because the reflux flowrate is too small to provide the minimum wetting required for the packing. The section is also narrower than the stripper main section because of the lower liquid flowrate compared to the stripping section.

The CO₂ stripper overhead gas is partially condensed from approximately 94°C and 1.95 bara to 25°C and 1.75 bara in the Overhead Condensers. The partially condensed two-phase mixture gravity flows to the Reflux Accumulator where the two phases separate. The reflux water is collected and returned via the Stripper Reflux Pumps to the CO₂ stripper rectification section. The CO₂ product gas from reflux accumulator is piped at 25°C and 1.65 bara to the Compression and conditioning plant. The reflux is pumped back on level control to the top of the CO₂ stripper and a small portion of the reflux flow is sent to the IX Package.

Amine Filtering

The amine may pick up dust or other insoluble contaminants as it flows through the various unit operations comprising the Carbon Capture Plant system design. Such contaminants could, in the long run, accumulate in the Ion Exchange (IX) column or foul the heat exchanger surface areas. Hence, a cartridge type filter will process a slip stream of lean amine pumped from the lean amine tank to the absorber to remove any entrained suspended solids.

The filtered amine will then flow to the Ion Exchange Unit (IX), when required or back to the Lean Amine Tank when the IX unit is not processing amine. Filtered amine can also be sent directly to the Thermal Reclaimer Unit (TRU) if the IX is not in operation.

As the concentration of suspended solids is expected to be low, it is unnecessary to install a back-up filter for use when replacing cartridges in the main filter.

Ion Exchange (IX) Unit

Trace contaminants present in the flue gas, such as SO_2 & NO_2 , form ionic Heat Stable Salts (HSS) that must be removed from solution. The IX unit is designed to remove HSS from the DC Absorbent. Although a certain level of HSS is tolerable within the absorbent, excess HSS must be removed. Excess HSS removal is achieved by use of the IX unit. The IX is also designed to remove small amounts of HSS formed due to oxidative amine degradation (mainly organic acids). Note that the National Transmission System (NTS) specification has up to 50mg/m^3 sulphur in the natural gas fired in the GTGs.

The CO₂ IX unit process is a batch process which involves five main steps:

- 1. Salt Loading
- 2. Amine Recovery Rinse
- 3. Buffering Rinse



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4. Regeneration with caustic soda

5. Excess Caustic Rinse.

Together, these five steps constitute an IX cycle.

Salt Loading

During the salt loading phase, the lean amine is passed through the IX Amine Cooler before being sent to the ion exchange column. The amine enters the bottom of the column and flows in an upward direction and the HSS adsorb onto the active sites of the resin. The purified lean amine exits the column with a lower salt concentration, and is piped back to the lean amine tank / thermal reclaimer unit. Once all of the resin active sites are occupied by the HSS, the resin is saturated and is no longer capable of further salt adsorption. The amine fed to the IX column is filtered through a cartridge-type filter.

Amine Recovery Rinse

After the salt loading phase, some of the amine remains trapped in the interstitial spaces between the resin beads and in the expansion volume of the bed. Before the resin is regenerated, the column is rinsed using reflux to recover the remaining amine in the column. The reflux is passed in a down flow direction, which displaces the trapped amine. The reflux is heated in the IX reflux heater and stored in the IX reflux tank before being pumped to the IX unit. The diluted lean amine is piped back to the lean amine tank.

Buffering Rinse

After the amine recovery rinse phase, an additional volume of heated demineralised water is introduced at the top of the column to increase the recovery of amine which is piped back to the lean amine tank.

Regeneration

A 4% by weight NaOH solution is made using 47% by weight NaOH solution. The 47% by weight NaOH solution from Caustic Soda Tank is sent to the inline mixer where it is blended with heated demineralised water from IX Demineralised Water Heater.

The demineralised water is pre-filtered using a cartridge-type filter. Furthermore, the 4% by weight NaOH solution is filtered before it is introduced at the top of the ion exchange column. During this phase, the HSS are removed from the resin and the resulting effluent, containing HSS and residual amounts of NaOH, is discharged as waste effluent.

Excess NaOH Rinse

After the regeneration phase, heated demineralised water is sent again at the top of the ion exchange column to displace the NaOH solution remaining within the resin bed. This dilute NaOH solution that contains HSS is also discharged as waste effluent. After this phase, the column is ready for another IX cycle.

A Programmable Logic Controller (PLC) will control the opening and closing of all the automatic isolation valves, at every step of the batch process.

This batch process will last about 148 minutes and will be repeated at constant intervals up to 9 cycles per day, depending on the level of HSS in the lean amine. This in turn depends on the concentration of SO₂ and NO₂ in the flue gas entering the CO₂ absorber.

The number of daily batches will be set by the operator. As part of the operating process, it is proposed the concentration of HSS will be monitored via a lab testing regime which will be used to provide feedback on the selected frequency of the batch process.

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Thermal Reclaimer Unit (TRU)

In addition to ionic heat stable salts, amine also accumulates non-ionic amine degradation products over time which must be removed from the solvent by the Thermal Reclaimer Unit. The TRU consists of three columns.

A stream from the lean amine exiting the IX package is fed to the Thermal Reclaimer Unit (TRU) at 30°C and 3 bara. This stream will essentially consist of water, amine, non-ionic degradation products and residual CO₂. The non-ionic degradation products consist of heavy degradation products and light degradation products, both are to be removed from the amine and water. The first TRU column separates the light degradation products, the second and third TRU columns separate heavier degradation products.

On a continuous basis, amine is pumped out of the Reclaimer Feed Vessel and is heated up in a preheater from 30°C at 3.5 bara to 110°C using LP condensate. The pre-heated feed is flashed over a control valve and fed into the first thermal reclaimer column at 105°C and 1.23 bara.

The first reclaimer column consists of a rectification section and a stripping section. The feed is introduced at 105°C and 1.23 bara, to the top of stripping section where it is flashed, liquid flows to the stripping packing section whereas vapour flows upward to the rectification section. The rectification section is provided to get a separation between light degradation products and lean amine, and provide a separation between water and light degradation products.

The overhead vapour from the first reclaimer column, which mostly consists of water, is partially condensed in the Overhead Condenser from 105° C to 90° C. The partially condensed two-phase mixture flows to the Overhead Knock-out Vessel where the two phases separate. The reflux, which is mostly water, is pumped by the Thermal Reclaimer Reflux Pump partly to the rectification section of the column on a flow control and partly to the lean amine tank on a level control. The vapour from Overhead Condenser, consisting of water, CO_2 and light amine components, is sent to the vent header.

The bottom of the first reclaimer column is heated with an insertion type reboiler, heated with MP steam. From the bottom of the first column, amine and heavier degradation products are sent to the second reclaimer column.

The second reclaimer column consists of a rectification section and a stripping section. The feed is introduced at 75°C and 0.12 bara, to the top of stripping section where it is flashed, liquid flows to the stripping packing section whereas vapour flows upward to the rectification section. The overhead vapour of this column, which mostly consists of amine, is condensed to 35°C and 0.09 bara and sent to the Overhead Knock-out Vessel. The non-condensable vapour, which is mostly air and remaining light degradation products, is sent to the vacuum package. A portion of the condensed amine is pumped by Thermal Reclaimer No.2 Reflux Pumps to the column on a flow control as reflux as determined by the required minimum wetting rates and the rest is sent on level control to the Degraded Amine Tank where it is mixed and cooled from 35°C with the degradation products separated from the first thermal reclaimer side stripper column. Diluted residues are periodically disposed of offsite, typically via incineration. Steam sparging is available at the base of the second reclaimer column to reduce viscosity and aid amine reclamation. The Steam Sparger Condensate KO drum receives LP steam from the Condensate Drum and removes any condensate before the steam is injected to the bottom of second reclaimer column. The bottom of the second reclaimer column is heated with MP steam using an insertion type reboiler.

The second reclaimer bottoms residue, which is mostly heavier degradation product, is pumped to Thermal Reclaimer Column No. 3 (C-2203).

The third reclaimer column also consists of a rectification section and a stripping section. The feed is introduced at the top of stripping section at 162°C and 0.12 bara where it is flashed, liquid flows to the





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stripping packing section whereas vapour flows upward to the rectification section. The overhead vapour of this column is condensed from 157°C to 35°C, and sent to the Overhead Knock-out Vessel. The non-condensable vapour, is sent to the Vacuum Package. A portion of the condensed amine is pumped by Thermal Reclaimer No.3 Reflux Pumps at 35°C 1.04 bara, to the column on a flow control as reflux as determined by the required minimum wetting rates and the rest is sent on level control to the Lean Amine Tank. The required duty of the thermal reclaimer pumps should be confirmed during Detailed Design, based upon the final layout. Steam sparging is available at the base of the third reclaimer column to reduce viscosity and aid amine reclamation.

The bottom of the third reclaimer column is heated with MP steam using an insertion type reboiler. Column pressure is kept at about 0.1 bara by a vacuum pump to operate with a bottom temperature of just under 200°C.

CO₂ Compression Process (First Section)

The compressor will be a multi-stage, integrally geared, electric driven machine with Variable Inlet Guide Vanes (VIGVs). The number of compressor stages and the anti-surge loop control depend upon the selected compressor vendor design and associated control system adopted.

Seven to eight compression stages will be required with 5 stages in the low pressure section and 2-3 stages in the high pressure section with common anti-surge control for each section.

For the first compressor stages, intercoolers are integrated with the separators (using extended surface coolers). Based on received vendor information, the extended surface coolers can be used for process pressures of less than 40 bara. Non-integrated shell and tube heat exchangers are used for higher process pressures in the last three compression stages.

Water-saturated CO₂ gas (containing approximately 1.8 mol % water) at 1.13 bara, 24°C flows from the capture plant to the First Compression Stage Knockout Drum, where any potential liquid carryover is removed and sent back to the capture unit, together with all liquid water collected from other compression stages and dehydration packages.

CO₂ gas is compressed in the first section to 41.5 bara before it is routed to the Reactor Pre-Heater. CO₂ gas at the outlet of each stage is cooled down to around 36°C by using cooling water with inlet temperature of 20°C. This is achieved in 1st/2nd/3rd Compression Stage Integrated Suction Knockout Drums Self-Draining Heat Exchangers. Condensed water in each stage is sent back to the previous stage knockout drum and finally all water is collected in the first Compression Stage Suction Knockout Drum and pumped to the Capture unit.

Dehydration System

A dehydration system, located after the fourth or fifth compression stage, is used to dry the CO_2 gas saturated with water. The dehydration system consists of two beds, one of which is operational whilst the other is being regenerated. Water-saturated CO_2 gas passes through a packed bed containing a solid desiccant like molecular sieve pellets or alumina silicate. The water vapour from the gas stream is adsorbed onto the solid desiccant and the CO_2 gas leaves the bed containing less than 10 ppmv of water vapour.

After a period of time the molecular sieve bed becomes spent, is taken offline and regenerated by heating the bed using dry hot CO₂ gas. The system has a regeneration loop consisting of a blower, heater (electrical/or steam), cooler/condenser and knockout drum.

The hot saturated CO₂ from the regenerating bed is cooled and condensed water is removed. Cooled saturated CO₂ gas is returned to the inlet of the dehydration package to mix with the feed gas. Once the



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regenerating bed has been dried (indicated by the bed temperature becoming hot) CO₂ gas at ambient temperature is passed through the bed to cool it down before it is put back online.

Dry CO₂ gas from the dehydration unit is filtered in a 100 % duty standby arrangement to remove particulates before sending to the Fourth or Fifth Compression Stage Knockout Drum.

CO₂ Compression Process (last two / three stages)

Dry CO₂ gas from the dehydration unit is compressed from 37.2 bara in the high pressure section of the compressor.

Dry CO₂ gas is further compressed in the final compression stage where CO₂ is in dense phase and then cooled down below 25°C in the Aftercooler. This cooling is important to reduce the likelihood of running ductile fracture occurring in the offshore pipeline. The gas flow rate is measured and analysed in a metering and analyser package, located after the Aftercooler, before entering the CO₂ export pipeline.



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Plant Utilities

The following utilities will be provided for the overall CCGT and CCC Plant:

- Natural gas fuel system, including inlet pipeline, metering, and pig receiver
- Utility steam and condensate
- Demineralized water system consisting of onsite trailers and offsite regeneration
- Water for domestic purposes will be provided by the local water utility
- Water and wastewater systems (Treated process waste water will be sent to the Municipal waste water system).
- Sanitary waste water will be sent to the Municipal sanitary system
- Service water/fire water and demineralized water storage
- Instrument/service air system
- Hydrogen
- Nitrogen
- · Fire protection system
- Piping system
- Electrical power distribution system
- Emergency Diesel Generator
- Instrumentation and control systems

LP and MP Steam

The purpose of the LP steam and condensate system is to provide the CC Plant's heat requirements for the CO₂ Stripper Reboiler units. LP Steam is supplied by the Power Plant via uncontrolled extraction from the LP Stage of the STG. After heat recovery in two process heat exchangers the condensate is sub-cooled before being returned to the Power Plant.

LP Steam will be de-superheated within the Power Plant to reach the battery limit conditions of 3.2 bara and saturation temperature. The steam at the battery limit between Power Plant and CC Plant will be superheated which will minimise the formation of condensate in the steam pipe during operation. Steam warming drains, vents and steam traps will be provided to ensure any condensate formation, particularly at start-up, is safely collected and removed to avoid erosion other damage to the system components.

MP steam from the Power Plant is used as the heating medium in the amine TRUs, with condensate being returned to the auxiliary boilers. The CO₂ vaporiser, located in the conditioning and compression plant area, is an occasional user of MP steam.

Waste Water Treatment Plant

The flue gas from the HRSG is routed to the DCC for cooling from 70°C to 30°C. Due to some unavoidable ammonia slip from the SCR, the flue gas will contain traces of ammonia that dissolve into the condensed water in the DCC. The effluent from the bottom of the DCC therefore contains ammonia and needs to be treated before it can be discharged.

A second stream to be treated is the acid-wash originating from CO₂ Absorber. This flow contains sulphuric acid with small quantities of dissolved amine.

In addition Ion Exchange effluent is treated together with these other waste streams.

The other waste liquid effluents of the whole plant are handled as follows:

• The rain water run-off goes to the open drainage system;

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- Dirty service and maintenance water will be discharged separately either to a local sewage system;
- Oily water will be discharged to the closed drains system;
- CO₂ compressor condensates are routed back to the capture process (absorber);
- Closed amine drains will be filtered and recovered back into the carbon capture process;
- Closed degraded amine drains in the TRU area will be collected and sent to the degraded amine tank for offsite disposal;
- Open chemical drains (water that might be contaminated with dilute amine, dilute chemicals) will be collected and pumped to the waste water treatment;
- Caustic drains will be collected in a local sump and removed by vacuum truck; and
- Effluent from the Thermal Reclaimer Unit is sent to the degraded amine tank for offsite disposal.

The concentrated toxic Acid Wash Effluent requires to be buffered in a tank before being sent to the Effluent treatment plant. The buffer tank can be topped up with potable water if required to dilute the Acid Wash Effluent. Acid Wash Effluent contains the highest concentration of pollutants and hence the flow to the WWTP of this stream must be carefully controlled by use of metering pumps.

All the incoming effluents are combined with the metered flow from the Acid Wash Effluent Buffer Tank. The incoming effluent is screened to prevent debris entering the plant: the screened material is dumped in a skid for disposal. Once screened the effluent is sent to a equalisation tank. The effluent flows are not constant and therefore the balance tank allows for flow fluctuations into the Waste Water Treatment Plant whilst maintaining a relatively constant flow for treatment. The tank includes a mixer such that the balance tank also allows mixing of the incoming effluents to provide a more consistent feed for treatment.

Acid and caustic are added to the balance tank as required to correct the pH of the effluent before treatment.

An emergency dump tank is provided to take out of spec effluent which cannot be treated by the Waste Water Treatment Plant (e.g. following an accident or incident). The dump tank will have tanker loading facilities such that this out of spec effluent can be transported to an offsite contractor for specialist treatment and disposal.

A biological treatment process is used to convert amines to ammonia, and then to convert ammonia to nitrogen. Activated sludge containing the biological agents is mixed with the effluent. The conversion takes place in a number of aeration, mixing, and settling steps. Gravity followed by a membrane separator is used in the final step of the process to separate the biological agent from the treated water: the activated sludge is recycled back to the start of the process.

The treated water is "polished" in a final reverse osmosis step to provide a discharge which complies with outfall environmental limits. The discharge from the water treatment plant will flow to an observation tank or basis where it will be monitored / sampled for compliance: off spec discharge will be recycled to the buffer tank for further treatment. Treated water will either be reused on the plant for cooling water or make-up water, or will flow to a licensed outfall.

Facilities

The following facilities will be provided:

- Guardhouse
- Offices & admin building
- Control room
- Training



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- Work shop(s) and lay down
- Stores & Warehousing
- Toilets, Showers, Lockers, Messing facilities for operations and maintenance personnel
- Local Equipment Rooms & Substations



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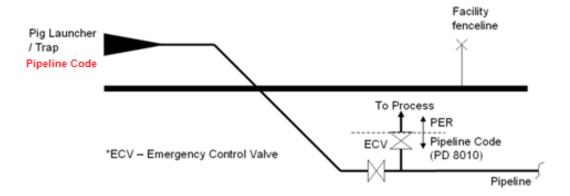
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Transport

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Onshore Transport

The onshore transport system starts at the discharge of the CO₂ Compression and Drying units. There is a short run of pipeline into the permanently installed Pig Launcher. The pipeline designation begins as per the diagram below.



Plant to Pipeline Demarkation (ref SNC-Lavalin procedure 4002-HCPR-LON)

The Pig Launcher will facilitate cleaning and inspection of the CO₂ Pipeline.

The onshore pipeline will be supplied with Cathodic Protection in order to mitigate corrosion.

The CO₂ pipeline will run underground from the edge of the CCGT and CCC Plant to the shore crossing point.

Above Ground Installations (AGI)

Depending on the length of the pipeline a number of AGIs may be required.

Isolation Valve Stations

Isolation Valve Stations are required periodically along the onshore pipeline length should the pipeline length exceed 10-20 km. The Isolation Valve Stations are required in order to isolate a section of pipeline following an incident in order to limit the inventory of CO₂ which can leak and to isolate a section of pipeline for maintenance / repair.

The Isolation Valve Stations are unmanned.

The scope of each Isolation Valve Station would be:

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- Power actuated (Electro-Hydraulic) isolation valve with associated valves and piping for required emergency sectionalisation
- Pressurisation bypasses to enable start-up from a depressurised state
- Connection pipe work and supports
- Valves for maintenance isolation
- Thermal or pressure relief valves (if required)
- CO₂ vent for pipeline section height set to allow safe dispersion
- Local and remote monitoring, control and shutdown systems designed for unmanned operation
- Telemetry for remote supervisory control monitoring and shutdown
- · Civil foundations, grading, plinths, maintenance and access paving, and security fencing

Booster Compression Station

A Booster Compression Station will be required near the shoreline should the pressure drop in the CO₂ pipeline exceed that allowed to meet the required pressure at the offshore facilities. The requirement will be a function of the pipeline length.

The Booster Compression Station would be unmanned.

The scope would include:

- Motor driven centrifugal compressor(s)
- Air cooled heat exchangers
- Inlet and discharge drums (if required)
- Compressor ancillaries, instrumentation, and unit control panels (including anti-surge)
- Compressor utilities e.g. instrument air package
- Connection pipe work and supports
- Valves for maintenance isolation
- Thermal or pressure relief valves
- CO₂ vent for pipeline section (with heating) height set to allow safe dispersion
- Fire detection and suppression system (lube oil or electrical fires)
- Pig receiver and pig launcher so can pig onshore and offshore sections of pipeline separately
- Compressor building (for aesthetics and acoustic control)
- Electrical Substation and LER
- UPS suitable for supporting control and telemetry for at least 1 shift
- Day crew facilities complying with Construction Welfare Regs and H&SW Regs (e.g. Toilets, Messing, Lockers, Showers, Potable Water, Sewage, HVAC)
- Local and remote monitoring, control and shutdown systems designed for unmanned operation



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- HIPPS if demonstrated by SIL review
- Metering (if CCC Plant battery limit is not sufficient e.g. if multiple pipeline users)
- Telemetry for remote supervisory control monitoring and shutdown
- CCTV, Access Control (ACS), and Security Systems
- Civil foundations, grading, plinths, maintenance and parking and access paving, and security fencing

Shore Crossing

A short onshore section of pipeline would connect the Booster Compression Station to the beach.

The interface between the onshore and the offshore pipeline would be the tie-in location between the two pipeline sections. The tie-in would be constructed in a cofferdam on the shoreline; the beach would be reinstated after completion of construction.

Offshore Pipeline

A subsea pipeline would connect the shore with the offshore facilities.

The subsea pipeline would be provided with a sacrificial anode system to mitigate corrosion.

A tie-in spool would connect the end of the pipeline to the bottom of the riser at the offshore platform. The offshore pipeline scope would end at the top of the riser at a dead weight support on the offshore platform: however, the pipeline code will be applied up to the topsides ESV and include the temporary pig receiver.

An SSIV would be provided to isolate the platform in case of riser damage: this is to isolate the platform from the subsea pipeline and limit the CO₂ release in case of loss of pressure integrity of the riser following a ship strike. This is ALARP design in order to reduce risk of toxic or asphyxiation casualties on board striking vessel due to engulfment by released CO₂.



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Offshore Facilties

The following content has been developed from the White Rose Document "K37: Offshore Infrastructure and Design Confirming the Engineering Design Rationale", January 2016 revision. This document contains public sector information licensed under the Open Government Licence v3.0. The open license is available under https://www.nationalarchives.gov.uk/doc/open-government-licence/version/3/.

Platform

It is assumed that the offshore platform will consist of a conventional structural steel jacket with an unmanned minimum facilities topsides.

This assumed facilities construction is based on the typical solution for near North Sea and Irish Sea facilities (i.e. water depth < 100m).

The assumed unmanned minimum facilities type is based on the low complexity of the offshore process and low level of subsequent maintenance requirements (compared to a Hydrocarbon production and separation platform).

The offshore platform will include a temporary pig receiver and the CO₂ injection wells which store the CO₂ into the saline or depleted hydrocarbon formation of the storage site.

Jacket

The substructure will be a fixed four leg jacket which will support the appurtenances, the topsides, and support drilling and well intervention operations.

Sacrificial cathodic protection system.

Foundations to seabed will be by eight skirt piles; two per corner leg.

The jacket will house the following appurtenances:

- CO₂ Import riser;
- J-Tubes for control;
- J-Tubes for power supply;
- Caisson for water disposal;
- Seawater lift caisson.

Topsides

The topsides scope will include:

- Riser isolation valve;
- Temporary pig receiver;
- CO₂ Filtration;
- CO₂ Metering per well;
- CO₂ Injection Well Manifold;
- CO₂ Injection Well Heads;

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- CO₂ Vent (height for safe dispersion);
- Wellhead Hydraulic Power Unit;
- Water Wash Package;
- MEG Injection Skid;
- Temporary Safe Refuge (TSR) including emergency overnight accommodation package unit with LER;
- Utilities:
 - Fresh Water (storage and supply only assume visiting teams bring potable water with them);
 - Diesel fuel bunkering;
 - Chemical injection (e.g. corrosion inhibitor);
 - Seawater lift pump (intermittent service no spare installed);
 - o Power Gen (Emergency Diesel Engine Driven Generation Set);
 - UPS (for safe shutdown of platform on loss of main and emergency power);
 - Nitrogen Quads;
 - Drains (Open and Closed) the open drains system will have a separator to direct oily water to the closed drains system. Closed drains system to be directed to a dump tank to be routinely pumped out by support vessel. The closed drains system to collect fluids which cannot be discharged to sea: pump lube oil, emergency gen set lube oil, power supply transformer oil, etc: this should be a small volume only for the CO₂ Injection Platform.
- Wellhead platform support systems:
 - o Crane;
 - Local equipment room (LER), switchroom, and battery rooms packaged with accommodation;
 - Nav aids;
 - o Telecoms;
 - Boat landing (or walk-to-work);
 - o Helideck.
- Safety systems:
 - Fire and CO₂ gas detection systems;
 - Helideck foam system;
 - o Fixed automatic fire fighting for electrical systems and emergency generation;
 - Survival craft (assumes team transported in by helicopter without support);
 - Emergency evacuation (doughnut type);
- Water disposal caisson;
- Laydown for temporary wireline equipment;

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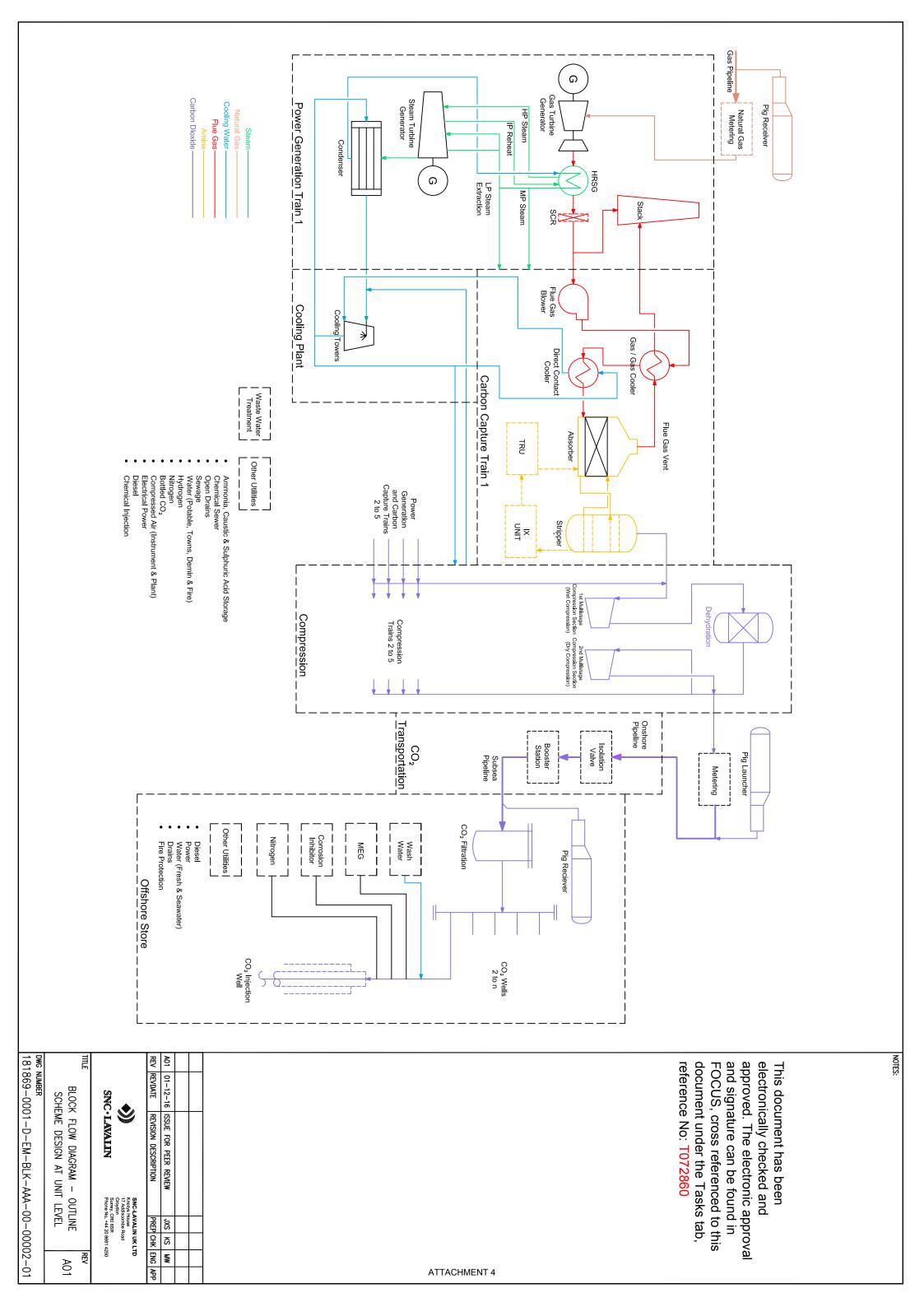
- Local and remote monitoring, control and shutdown systems designed for unmanned operation;
- HIPPS if demonstrated by SIL review;
- Telemetry for remote supervisory control monitoring and shutdown;
- CCTV, Access Control (ACS), and Security Systems;

Water wash treatment facilities to avoid halite build up when CO₂ injection is shut-in (seawater lift pumps and caisson, filters and chemical treatment). Additional water wash facilities will be provided by a temporary skid (injection pumps, filters, power generation and chemicals).

The Temporary Safe Refuge is required in order to cope with adverse weather conditions preventing evacuation or CO_2 release. A CO_2 release case will require the TSR to be gas tight and support the team size for the duration of the event: this may require supplementary bottled compressed breathing air provision if the air volume in the TSR is not sufficient. There will be an evacuation route from the TSR to the helideck and the survival craft. TSR to comply with UK offshore safety regulations.

Block Flow Diagram

181869-0001-D-EM-BLK-AAA-00-00002-01



Roll Out Trajectory

181869-0001-T-EM-TNT-AAA-00-00003



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Document No.: 181869-0001-T-EM-TNT-AAA-

TECHNICAL NOTE

00-0003

From: Matt Wills Date: 21-Dec-2016

Project: Thermal Plant with CCS: Generic Business Project No.: 181869

Case

The ETI

Subject: Roll Out Trajectory

Distribution: AECOM

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Introduction

A high level process scheme has been agreed with the ETI at a meeting on Thursday 27th October 2016.

This document is description of the potential roll out of the project of the scale agreed with the ETI.

The high level process scheme can be seen in document Block Flow Diagram - Outline Scheme Design at Plant Level, number 181869-0001-D-EM-BLK-AAA-00-00001-01.

Obstacles to Development

Discussions with some of the stakeholders within the CCS arena has revealed a sense of bitterness and frustration with regards to the deployment of CCS within the UK market. The UK government has commissioned two rounds of commercialisation competition: whilst these have produced a wealth of data they have not yet yielded a working commercial scale CCS plant.

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Obstacles identified to deployment of a commercial scale CCS plant:

- Cross chain default risk CCS projects have tended to be made up of several companies each
 responsible for a link in the chain (e.g. power generation company, carbon capture company,
 transmission company, offshore storage entity). Investors in CCS projects do not want to be financially
 liable for a failure to deliver of one of the other companies in the chain as the revenue will tend to be
 dependent on CO₂ being sequestrated.
- Storage Liability offshore CO₂ injection facilities may have lives of 10 years (e.g. Goldeneye) to 50 years (Forties) according to the Pale Blue Dot Report. However, the liability for the CO₂ stores will continue long after the offshore facilities have been decommissioned.
- Funding for the additional expenditure for carbon capture and storage infrastructure and operation. The CCS infrastructure adds considerably to the CAPEX and OPEX compared to an unabated plant: how is the additional costs for CCS paid for and made competitive?
- Uninsurable risks there are certain risks associated with the early stages of the CO₂ capture and storage industry for which there is not sufficient data / knowledge for insurance companies to price and cover. Also, overlapping with the storage liability above, there are risks that are deemed uninsurable for which the UK government would have to be insurer of last resort.
- Transportation infrastructure investors will likely only invest in transportation and storage infrastructure for their project (why take the financial burden and risk for someone else's project?). Multi project development will need a higher flow rate transportation trunk with hubs and branches: Lord Oxburgh has recommended that government take ownership of such a network.
- CCS Fatigue Investors, Potential Operators, OEMs, Technology Providers, Contractors, and Consultants have put a lot of effort into previous rounds of CCS development. Whilst the government has covered some of the costs the stakeholders have generally invested a lot of their own funds without commercial return as none of the commercial scale plants have been realised. There are difficulties in securing further interest in CCS as decision makers in stakeholders are reticent in committing further resources until the UK Government is committed to, and has decided on a funding mechanism for, future CCS projects. (Never-the-less, after a decade of personal commitment, the engineers involved would all like to see a successful CCS project).

Roll Out Plan

The previous DECC Commercialisation Competition has been cancelled. This would have resulted in a commercial CCS plant in operation by 2020. The FEED studies for 'White Rose' and 'Peterhead' projects have been published ('KKDs') by DECC including some of the learnings from the work undertaken.

Whilst policy is still to support low carbon plants the UK Government has withdrawn capital support for CCS projects. The Contracts for Difference (CfD) instrument remains the most likely solution to supporting a Thermal Power with CCS project, although the Oxburgh report recommends that the UK Government takes ownership of a CO₂ transportation network. The state of the UK finances following the fall out from the Brexit decision, and the uncertainty of how Brewit will play out makes it unlikely that the UK Government will be able to commit capital investment to near term projects.





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CfD has been used to support the development of new nuclear power, biomass, wind power generation, and other low carbon technologies. The Generic Business case project will assume that a CfD mechanism would be used to support the development of a Thermal Power + CCS project.

1st Plant Development

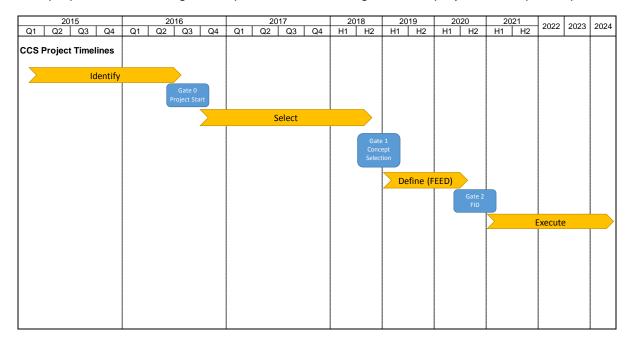
The work carried out by the ETI suggests that a strategic push for a large scale plant would be an attractive proposition:

Strategic push	Press ahead with large scale (up to 3GW), low risk projects by mid 2020s Gas post-combustion	Progress to 3GW by 2030, at lowest unit cost, but requires strong policy commitment, risk sharing & attractive contract
	Locate near low cost, well-developed storage	

The technology deployed needs to be 'bankable' in order to secure investment funding: the work carried out by the ETI shows that debt funding is far more advantageous to CCS deployment than marginal improvements in efficiency. This results in the following high level technology selections:

- Class H / J Combined Cycle Gas Turbines (CCGT): the CCGT plants currently being deployed have an efficiency of approximately 62%.
- Post Combustion Amine Carbon Capture: Shell Cansolv technology has been deployed at the Boundary Dam plant operated by Saskpower.
- Dense phase CO₂ transportation: there are hundreds of CO₂ compressors deployed worldwide for high pressure CO₂ operation.

The ETI propose the following development timeline using standard project development phases:





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Follow On Plant Developments

The design of the 1st Plant Development does not directly support further plants because the basis of design does not include the investment in transportation and storage infrastructure to support additional large volumes of CO₂.

The 1st Plant Development would only indirectly support further developments by showing the operational and commercial viability of a Thermal Plant with CCS.

Project Design Basis

181869-0001-T-EM-DBS-AAA-00-00001









BASIS OF DESIGN

Document No: 181869-0001-T-EM-DBS-AAA-00-00001

1 OF 14

Revision: A03 Date: 01-DEC-2016

This document has been electronically checked and approved. The electronic approval and signature can be found in FOCUS, cross referenced to this document under the Tasks tab, reference No: T072859.

A03	01-DEC-2016	Issued for ETI Approval	M.W.	K.S.	S.B.	M.W.
A02	11-NOV-2016	Issued for ETI Review	M.W.	K.S.	S.B.	M.W.
A01	09-NOV-2016	Issued for Peer Review	K.S.	M.W.	S.B.	M.W.
REV	DATE	ISSUE DESCRIPTION	BY	DISC CHKD	QA/QC	APPVD

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REVISION	COMMENTS
A01	Issued for Peer Review
A02	Issued for ETI Review
A03	Issued for ETI Approval Changes are indicated by a bar on the right hand side of the text

HOLDS				
HOLD DESCRIPTION / REFERENCE				

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A03

01-DEC-2016

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BASIS OF DESIGN

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1.0 INTRODUCTION

1.1 Purpose

This document is a high level Basis of Design for the Thermal Power with CCS: Generic Business Case produced in order to provide the minimum definition required for Engineering Modelling and Cost Modelling work to be undertaken for the Generic Business Case.

High level information is used as a description because this Basis of Design needs to be only detailed enough for conceptual level works.

1.2 Scope

The Generic Business Case aims to capture around 10 million tonnes of CO₂ per annum from Combined Cycle Gas Turbines (CCGT). The overall plant configuration is expected to be as follows:

- · Gas inlet to the CCGT's;
- 5 Combustion Turbines Nominal total capacity 2.5 GW (each 500MW);
- 5 Heat Recovery Steam Generators (HSRG);
- 5 Steam Turbines (ST) Nominal total capacity 1000 MW (each 200 MW);
- Flue gas treatment, with Selective Catalytic Reduction (SCR), for NO_x removal;
- 5 Carbon Capture (CC) Units, i.e., there will be one CC Unit for each CCGT train;
- 5 CO₂ Compressors;
- CO₂ pipeline, with valve stations, for dense phase CO₂ transport to the shoreline;
- Shoreline compressor station, if required;
- Subsea CO₂ pipeline; and
- Offshore Platform.

The design basis given in this document covers the whole CCGT with CCS scheme for the plant. Please refer to the Block Flow Diagram, 181869-0001-D-EM-BLK-AAA-00-00001-01, for additional details.

1.3 Definitions

The Combustion Turbines will fire natural gas to power the generators and raise steam through the HRSG's. The steam from each HSRG is routed to a steam turbine. Flue gas, after treatment for NO_X removal, is routed to a CC plant, which use amine solvents, to capture 90% of the CO_2 in the CCGT flue gases. The captured CO_2 is recovered from the amine by steam stripping, compressed and conditioned before being transported via a pipeline to offshore for storage. The end to end chain links for the overall plant are:

- · Power generation facilities including flue gas treatment
- Carbon capture, compression and conditioning
- Pipeline and transport
- · Offshore storage

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Key definitions relevant to this chain links are:

Capture efficiency - This is the percentage of CO₂ recovered from the flue gases entering the CCS plant.

Dense Phase - CO₂ above its critical temperature and pressure. This state is referred to as dense phase fluid, or supercritical fluid, to distinguish it from normal vapour and liquid.

Nominal Capacity - This is the target power output of the machines; it is not a reflection of the actual power output from the machine.

Plant – The overall CCGT and CCC facility including up to 5 trains.

Train - 1 Combustion Turbine, 1 HRSG, 1 ST, 1 CCC.

Unit – Each power or process block: these are the sub-units of each train.

1.4 Responsibility

The Chief Technologist (CT) is responsible for creating and maintaining this document for the duration of the Contract.

2.0 ABBREVIATIONS

Abbreviation	Description
СС	Carbon Capture
ccc	Carbon Capture and Compression
CCGT	Combined Cycle Gas Turbine (Gas Turbine + Steam Turbine)
ccs	Carbon Capture and Storage
СТ	Chief Technologist
ETI	The Energy Technologies Institute
GW	Giga watts
GT	Gas Turbine
HSRG	Heat Recovery Steam Generator
ICF	Incomplete Combustion Factor
IEAGHG	International Energy Agency Greenhouse Gas R&D Programme
mbar	Millibar
MW	Mega watts
ppmv	Parts per million by volume
RH	Relative Humidity
SCR	Selective Catalytic Reduction
SI	Soot Index

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Abbreviation	Description
ST	Steam Turbine
WN	Wobbe Number

3.0 REFERENCE DOCUMENTS

Document Number	Document Title
	Progressing Development of the UK's Strategic Carbon Dioxide Storage Resource – A Summary of Results from the Strategic UK CO ₂ Storage Appraisal Project.
0017246	Agreement for the provision of research services through a prime contractor normal power with CCS project - Generic Business Case
1.17.13074 rev A2	WP6 – CCS Benchmark Refresh Report 2013 – Phase A Report
181869-0001-D-EM-BLK-AAA-00-00001-01	Block Flow Diagram - Outline Scheme Design at Plant Level
K30	Storage Process Description
K43	Field Development Report
PCCS-00-PT-AA-7704-00001, rev K06	Basis of Design for the CCS Chain

4.0 CODES AND STANDARDS

Document Number	Document Title
SI 1996 No. 551	Gas Safety (Management) Regulations 1996

5.0 PLANT LOCATION

5.1 Onshore

The CCGT + CCC site will be in the UK within the search areas defined in the Agreement number 0017246.

5.2 Offshore

The offshore facilities from Connah's Quay will be on the Hamilton Field in 24m water depth.

The offshore facilities from the East Coast of England will be on the Endurance Field in 59.3m water depth.

6.0 ONSHORE SITE CONDITION

An obstruction free site (both under and above ground) is assumed without the need for any specialised civil works.

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7.0 PLANT CAPACITY

The CCGT power generation facilities will be designed to produce, and deliver, around 3.5 GWe (nominal gross capacity without CO₂ capture) of electric energy to the UK National grid.

The CCS facilities will be designed capture and store around 10 million tonnes of CO₂ per annum.

Plant turndown is 50% for each CCGT/CCC train. This could be based on either the minimum fuel gas feed to the CCGT, or the minimum CO_2 injection rate to the wells. However, the overall plant turndown will be lower since the plant operates with multiple trains. For example, the turndown will be 20% if only one out of the five (5) trains runs (operates).

8.0 CLIMATIC CONDITIONS

8.1 Onshore

Site climatic conditions given below shall be considered reference conditions (*) for plant performance and evaluation.

	Average	Maximum	Minimum
Atmospheric Pressure, mbar	1013 (*)	1045	960
Relative Humidity, %	60 (*)	95	40
Ambient Temperature, °C	10 (*)	30	-10
Wet Bulb Temperature, °C	7 (*)	29	-13

Source: WP6 - CCS Benchmark Refresh Report 2013 - Phase A Report, revision A2

8.2 Equipment Performance Design Temperatures:

Ambient air design temperatures for equipment design:

- Gas Turbines 18°C @ a RH of 65%
- Air Coolers 30°C

8.3 Offshore

	Average	Maximum	Minimum
Atmospheric Pressure, mbar	1013	1044	960
Relative Humidity, %	6	95	40
Ambient Air Temperature, °C	8	20.6	-3.4
Ambient Sea Temperature, °C	10	19.4	4.2

Wave Height = 17m

Un-drained Shear Strength, Cu = 75 kN/m² (Firm Clay)

Current Velocity = 1.1 m/s

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Calibration Factor = 1.15 (WD < 150m)

Average Marine Growth = 0.05m

9.0 DESIGN LIFE

The design life of the CCGT with CCS plant will be 25 years.

The design life of new CO₂ transmission and storage infrastructure will be 40 years.

The design life of reused CO₂ transmission and storage infrastructure will be 15 years.

10.0 CARBON DIOXIDE CAPTURE RATE

Each carbon dioxide abated case will be designed to achieve a target carbon capture level of at least 90%, defined as:

 CO_2 Capture Rate (%) = 100 x moles carbon contained in the CO_2 product

moles carbon contained in the flue gas feed to CCS plant

Exceptions to 90% capture rate would be:

- Part load operation
- Start up / shut down
- Ramping
- Emergency

11.0 FEEDSTOCK AND UTILITY SUPPLIES

The streams available at plant battery limits are the following:

- Natural gas;
- Plant/raw water:
- Potable water:
- Power supply (black start);
- Bottled gases (hydrogen, nitrogen) and;
- Chemical supply (by Road Tanker including amine and demin water).

Other utilities, including boiler feed water, instrument and plant air, oxygen and nitrogen will be generated within the complex where necessary and will be available for use at the required conditions.

11.1 Natural Gas

Natural gas from the UK National Transmission System (NTS) is available as feedstock to the CCGT.

Natural Gas feedstock composition:

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Constituent	Mol%
Methane	87.45
Ethane	6.98
Propane	2.19
I-Butane	0.00
N-Butane	0.41
I-Pentane	0.00
N-Pentane	0.05
Neo-Pentane	0.00
I-Hexane	0.00
N-Hexane	0.02
Heptane	0.00
Octane	0.00
Nonane	0.00
Decane	0.00
Nitrogen	0.99
Carbon Dioxide	1.91
Hydrogen Sulphide	0.0037
Water	0.00

Source: Basis of Design for the CCS Chain, PCCS-00-PT-AA-7704-00001, rev K06. © Shell U.K. Limited 2015. Any recipient of this document is hereby licensed under Shell U.K. Limited's copyright to use, modify, reproduce, publish, adapt and enhance this document.

Natural gas feedstock specification (as NTS spec):

H ₂ S Content	Not more than 5 mg/m ³
Total Sulphur Content	Not more than 50 mg/m ³
Hydrogen Content	Not more than 0.1% (molar)
Oxygen Content	Not more than 0.001% (molar)
Hydrocarbon Dewpoint	Not more than -2°C at any pressure up to 85 bar(g)
Water Dewpoint	Not more than -10 C at 85 bar(g) (or the actual delivery pressure)
Wobbe Number (WN) (real gross dry)	Between 47.2 MJ/m³ and 51.41 MJ/m³ (at standard temperature and pressure) and in compliance with ICF and SI limits
Incomplete Combustion Factor	Not more than 0.48
Soot Index (SI)	Not more than 0.60

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Gross Calorific Value (real gross dry)	Between 47.2 to 43 MJ/m³ (at standard temperature and pressure) and in compliance with ICF and SI limits, subject to a 1 MJ/m³ variation.
Inerts	Not more than 7.0 mol%, subject to: Carbon Dioxide content – not more than 2.0 mol% Nitrogen content – not more than 5.0 mol%
Contaminants	Gas shall not contain solid of liquid material which may interfere with the integrity or operation of pipes of any gas appliance within the meaning of the Regulation 2 (1) of the Gas Safety (Use of) Regulations 1998 that a consumer could reasonably be expected to operate.
Delivery Temperature	Between 1 C and 38 C
Odour	Gas delivered shall have no odour that might contravene the statutory obligation "not to transmit or distribute any gas at a pressure below 7 bar(g) which does not possess a distinctive and characteristic odour".

Source: Gas Safety (Management) Regulations 1996, Schedule 3, Part I

11.2 Closed Loop Cooling System

Cooling will be via a closed loop cooled cooling water system. All cooling services will be placed on this system. This system cools the closed loop water in a mechanical draft cooling tower. The make-up water to the system will be from estuary local water source.

Closed loop cooling water conditions:

Average supply temperature	13°C
Average return temperature:	23 [°] C
Cooling Tower Approach:	10°F
Operating pressure at users:	3.0 bar(g)
Maximum ΔP for users	1.5 bar

Cooling tower approach temperature taken from "Process Heat Transfer", D. Kern, ISBN 0-07-463217-5.

12.0 POWER

12.1 Black Start Power

National Grid electrical grid connection is available for "black start" power requirement scenarios.

No back up fuel (e.g. dual firing diesel) is considered for the design of the Plant.

12.2 Voltage/Phase/Frequency

The following voltage levels are to be used for the plant design:

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	Voltage	Phase	Frequency
Transmission	400kV / 275 kV / 132 kV	3	50 Hz
Generation	25 kV / 20 kV	3	50 Hz
HV Power	11 kV	3	50 Hz
LV Power	400 V	3	50 Hz
	230 V	1	50 Hz
UPS	110 V	DC	
Control	24 V	DC	

13.0 PRODUCT SPECIFICATIONS

13.1 Carbon Dioxide

Carbon Dioxide (CO₂) produced from the plant will be dried and compressed to 150 to 200 bar (g) for export (dense phase transport) from the facility to the well head of offshore reservoirs for storage. Product carbon dioxide conditions will be:

Pressure: 150-200 bar(g) - Note 1

Temperature: < 30°C

Note 1 - Pipeline length (onshore/offshore), well head pressure, etc., will set this requirement

The target carbon dioxide export specifications are:

Constituent	Specification
H ₂ O	≤ 50 ppmv
O ₂	≤ 10 ppmv
Volatile components	≤0.6 ppmv
H ₂	≤2% volume
Noxious components	Control to level that does not significantly affect the hazards posed by CO ₂ releases
Corrosive Components	General Specifications
Particulates	< 5 microns

Source: Basis of Design for the CCS Chain, PCCS-00-PT-AA-7704-00001, rev K06. © Shell U.K. Limited 2015. Any recipient of this document is hereby licensed under Shell U.K. Limited's copyright to use, modify, reproduce, publish, adapt and enhance this document.

The \leq 50 ppmv is consistent with the AmecFW CCS Benchmark Refresh Report, Longannet, Kingsnorth and ROAD Projects, and with the IEAGHG CO₂ Pipeline Infrastructure Report, January 2014.

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181869-0001-T-EM-DBS-AAA-00-00001 A03 01-DEC-2016 13 OF 14				
BASIS OF DESIGN				

The low O₂ composition has been specified to avoid material selection issues in the injection well tubing where the dry CO₂ contacts saline aquifer water. 5 ppmv was specified by the Peterhead project. 10 ppmv is consistent with the White Rose Project.

Hydrogen specification was increased to 2% volume per the White Rose Project, K02 Full Chain Basis of Design. This document contains public sector information licensed under the Open Government Licence v3.0. The open license is available under https://www.nationalarchives.gov.uk/doc/open-government-licence/version/3/

13.2 Offshore Reservoir Parameters

The following data shall be used for the injection design:

ENDURANCE

Well Size: 5 ½"

Injectability per Well: 1.34 MTPA

Well Head Pressure: 90 to 180 bar(g)

HAMILTON

Well Size: 9 ⁵/₈"

Injectability per Well: 2.5 MTPA

Well Head Pressure: 90 to 180 bar(g)

Sources: White Rose documents K43: Field Development Report and K30 Storage Process Description. These documents contain public sector information licensed under the Open Government Licence v3.0. The open license is available under https://www.nationalarchives.gov.uk/doc/open-government-licence/version/3/

And

Progressing Development of the UK's Strategic Carbon Dioxide Storage Resource – A Summary of Results from the Strategic UK CO₂ Storage Appraisal Project. © Energy Technologies Institute LLP.

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BASIS OF DESIGN				

14.0 ENVIRONMENTAL EMISSION BASIS

The overall gaseous basis for this study is as follows:

CCGT⁽¹⁾

NOx (as NO₂), mg/Nm³: ≤ 50

Particulate, mg/Nm 3 : ≤ 5

CO, mg/Nm³: ≤ 20

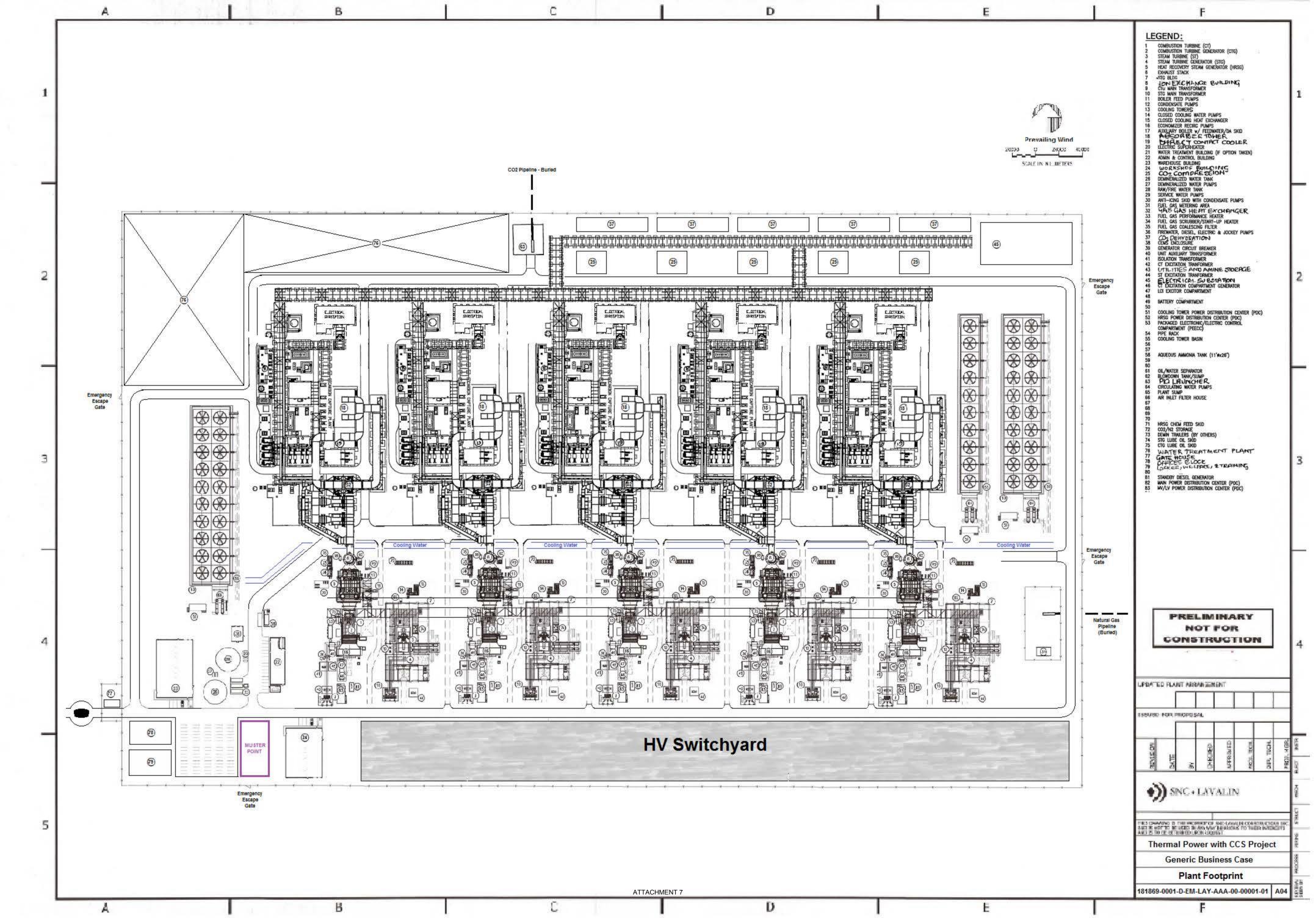
Notes:

(1) @ 15% O₂ vol. dry

Source: WP6 - CCS Benchmark Refresh Report 2013 - Phase A Report, revision A2

Plant Footprint

181869-0001-D-EM-LAY-AAA-00-00001-01





To:

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Document No.: 181869-0001-D-EM-LAY-AAA-

00-00001-01 Attachment 1

TECHNICAL NOTE

From: Matt Wills Date: 21-Dec-2016

Project: Thermal Plant with CCS: Generic Business Project No.: 181869

Case

ETI

Subject: Notes to Accompany the Plant Footprint

Distribution: AECOM

*** This document accompanies the Plant Footprint Drawing ***

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Introduction

A plant footprint is required in order to ascertain the space required for the Thermal Plant with CCS.

The plant footprint has been developed from source information as per the table in the following section.

The plant scheme follows the Block Flow Diagram - Outline Scheme Design at Plant Level, document reference 181869-0001-D-EM-BLK-AAA-00-00001-01, rev A03 (noting that it has been agreed that the maximum number of trains will now be 5).

The purpose of the Plant Footprint is to:

- Allocate space required for AECOM to search for suitable sites (WP2).
- Provide layout basis for cost estimation (WP3).
- Provide a basis for the photomontages (Variation Scope).

This document accompanies the Plant Footprint to clarify the decisions made to generate the drawing.





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Plant Footprint

Thermal Plant with CCS

The layout has been developed using the following source information:

Area	Source Information	Size	Comments
Power Generation	SNC-Lavalin drawing 8045 GA002-S002 rev B	580m x 145m	Plant Scheme is decided as a 1+1.
		(8.4 Ha)	Steam Turbine based on 2+1 steam turbine. 1+1 steam turbine will be slightly smaller – but does not affect overall plot as the Combustion Turbine spacing is determined by the Carbon Capture Units.
			The power plant layout is based on GE 9HA.02 Combustion Turbine and GE D600 Steam Turbine.
Carbon Capture	Peterhead Plot Plan (Overall CCCC Project	600m x 210m	© Shell U.K. Limited 2015. Any recipient of this document is hereby
	Area Plan), doc ref PCCS-00-TC-MP-4024- 00002 rev K01.	(12.6 Ha)	licensed under Shell U.K. Limited's copyright to use, modify, reproduce, publish, adapt and enhance this document.
			The plant layout is based on Shell Cansolv technology.
			Plot plan is same size as Peterhead. Know that the main equipment and ducting will be 25% dimensionally bigger for the duty: however, separation distances will be the same.
			There should be opportunity to optimise the design (can the stack be on top of the absorber?). Also some of the utilities are moved to a separate utilities area.
HV Switchyard	Google Maps views of Power Stations SNC-Lavalin drawing 8045 GA002-S002 rev B And	610m x 50m	Scaled from google maps views.
		(3 Ha)	
Cooling Towers		130m x 175m (2.3 Ha)	Cooling Towers have been grouped as requested by Chief Technologist form Weekly Meeting call on Friday 4 th November.
	181869-0001-T-EM- CAL-AAA-00-00001 summary table		





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Area	Source Information	Size	Comments
Water Treatment Plant	Peterhead Plot Plan (Overall CCCC Project Area Plan), doc ref PCCS-00-TC-MP-4024- 00002 rev K01.	and 105m x	Scaled up from Peterhead.
CO ₂ Compression and Dehydration	Peterhead Plot Plan (Overall CCCC Project Area Plan), doc ref PCCS-00-TC-MP-4024- 00002 rev K01.	40m x 150m (6 Ha)	Assume 5 x Peterhead for CO ₂ Compression and Dehydration
Utilities	SNC-Lavalin power plant bids	(1.6 Ha)	Distributed into two main areas.
Facilities	SNC-Lavalin power plant bids	(1.4 Ha)	
Total		820m x 495m	Additional space for roadways and
		~40 Ha	boundaries

Construction Laydown

Area	Source Information	Size	Comments
Power Generation	SNC-Lavalin proposals	12 Ha	4,000 m ² per 100 MW
Carbon Capture	Proposed Site Establishment and Laydown Area Layout, SNC-Lavalin drawing for Peterhead: PE15EF005UK-SK001 rev A	8 Ha	95m x 165m (1.6 Ha) for each Carbon Capture and Compression Train.
Total		20 Ha	

SNC-Lavalin would use large areas of the Plant Plot Plan as temporary construction lay down during the construction.

Cooling Tower, Utility, Water Treatment, Facilities, and Switchyard areas could be used as temporary lay down during the construction of the Power and Process Units: the construction duration of the Cooling Tower, Utility, Water Treatment, Facilities, and Switchyard areas will be much shorter than the other areas. On plot temporary construction lay down would allow roughly 10 Ha to be available through a lot of the construction program.

An allowance of 10 Ha is advised by SNC-Lavalin for Construction Camp and Laydown outside of the Plant Footprint. This would make the site requirement approximately **50 Ha**.

Should sites of only 40 Ha be practically available then these could be used, but with 10 Ha of offsite laydown located nearby to the site (not necessarily adjacent). SNC-Lavalin had planned this approach for



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some of the laydown for recent projects in the UK including our proposal for Shell Peterhead. Unfortunately post-industrial Britain has a large number of redundant industrial areas, factories, and warehouses which can serve as offsite construction laydown.



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Approach to Layout

The layout follows SNC-Lavalin standard document "Design Basis – Plant Layout (onshore)", document reference 000761-0016-T-PI-DBS-0001 rev C02.

Combustion Turbines

The Combustion Turbines are located upwind of the plant so that the prevailing wind does not carry contaminants or flammable releases into the combustion air inlets of the machines.

Steam Turbines

Steam turbines were originally located towards the side of the plant to minimise the cooling water pipe work runs from the condensers to the cooling towers. This was not the preferred solution. The steam turbines have been located adjacent to the gas turbines to minimise the length of the high pressure steam pipe work from the HRSG to the STG.

There will be long runs of cooling water pipe work around the plant, however, this is low pressure and standard materials as opposed to being high pressure and specialist metallurgy.

HV Switchyard

The HV Switchyard is located close to the generators. The plant edge location of this unit allows for HV power transmission lines to leave the plot without having to cross other process units.

Cooling Towers

Cooling Towers should ideally be located downwind of the Power and Process Plant so that the mist cloud from the towers will not contribute to the corrosion of the Plant, interfere with Electric / Instrument operation, obscure vision of the facilities, nor be ingested by Combustion Air Intakes.

However, this would extend the length of cooling water mains from the Steam Turbine Condensers. Instead, as a compromise, the Cooling Towers have been located crosswind from the plant.

The location of the cooling towers has been split in order to reduce the pipe runs from the STG condensers to the cooling towers. The cooling towers will be located either side of the Carbon Capture units.

Carbon Capture Plant

The Carbon Capture Plant includes CO₂ which poses a hazard to operating personnel. The Carbon Capture Plant is therefore located downwind from the Power Plant so that any leakage would not drift onto the Power Plant and any operators located in this area.

The location of this unit is also logical with respect to plant flow.

The CO₂ emergency vents will be located on top of the Amine Strippers.

Compression and Dehydration

The Compression and Dehydration Units include high pressure CO₂ which poses a hazard to operating personnel: the higher pressure increasing the zone affected by any leak and the time available to react. As a high hazard unit of the plant this is located downwind of the rest of the facility, away from manned areas, and at the extremity of the plant plot.

The developer should consider the societal risk impact posed by this unit to any activities on the other side of the site boundary.

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The location of this unit is also logical with respect to plant flow.

Utilities

The key utilities (e.g. fire fighting) will be located near the permanently manned areas of the plant for easy access. This location is also upwind of plant hazards. Dedicated consideration will be given to additional split of utilities in order to avoid common failures.

The remaining utilities are located between adjacent to the Cooling Towers. This is not an ideal location as it is not upwind of plant hazards (is cross wind): but this allows utilisation of an available area of plot.

Manned Areas

The permanently manned areas of the plant are near the plant entrance for easy access. This location is also upwind of plant hazards. Dedicated emergency gates will be provided to ensure safe evacuation of the plant for any operator in the field during an emergency.

Natural Gas

The natural gas intake to the plant is located on the right hand side of the CCGT Units and at the extremity of the plant. This high hazard zone (explosion) is located at the opposite end of the plant to the permanently manned area.

The location of the natural pig receiver and metering allows easy access of the pipeline from the edge of the plant (i.e. the pipeline does not need to pass under any process units. The fuel gas pipe work serving the gas turbines can then run underground (lower risk) or along the pipe rack serving the power generation plant.

Development - Inter discipline Review comments on A01 revision:

- Note 1. The cells in this size of cooling tower are compartmentalized. I believe you will need pumps for the individual condensers. **Space allowed.**
- Note 2. Grouped STG arrangement will not work. This arrangement with the side to side condensers is not possible as shown. I would at least double the spacing between the STG's to allow for circulating water connections and the double sided inlet and outlet steam piping. Also, there will be a set of bypass valves (Cold Reheat and LP Steam) for each STG. This will require quite a lot of room on the pipe rack side of each STG. **STGs located with individual Gas Turbines in 1 + 1 arrangement.**
- Note 3. This portion of the pipe rack shown in the drawing should be scaled up by at least 2 times, if not 2.5 times to accommodate all the various steam lines along with other services. **Included rev A02.**
- Note 4. This portion of the pipe rack shown in the drawing should be scaled up by at least 1.5 times, if not 2 times to accommodate all the various steam lines along with other services. **Included rev A02.**
- Note 5. It is my "gut" feeling that the CO₂ separation equipment is too closely spaced, especially for constructability. I have no experience with this equipment but this would be my general observation. **OK** refer to the technical note on Constructability (181869-0001-T-EM-TNT-AAA-00-01003).
- Note 6. The "fin fan" type cooler shown for the closed loop cooling circuit should be replaced with a plate and frame heat exchanger with the glycol loop on the plant side and cooling tower water on the other side. We have revised this GA to show a typical modularized unit and this change is included with this email, along with the revised GA for the air-cooled option. **Included in rev A02.**

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In general, the spacing of the Carbon Capture equipment is likely too close for good constructability. I would investigate spreading it apart. I would go back to a version of the power blocks with the STG's separated. I understand your reasoning for wanting them in one large block, but the piping will be a nightmare! Refer to the technical note on Constructability (181869-0001-T-EM-TNT-AAA-00-01003). STGs now located with each train.

Safety Review

Outcomes of the Design Safety Review conducted by Antonio Zanghi (Head of Design Safety):

- CO₂ pipeline must be buried as soon as possible after pig launcher.
- Natural Gas pipeline must be buried as soon as possible after pig launcher.
- Additional secondary road to the 'left' of each CCGT to ensure 360° access for emergency and fire fighting teams.
- Muster point to be located upwind of plant hazards.
- Locate emergency escape (crash) gates around perimeter of onshore plant to allow operators to leave plant in an emergency.
- Modify Entrance so that there is 2 sets of gates (2 step security) and traffic route direction change as anti-terrorism security in design.