Programme Area: Carbon Capture and Storage

Project: Thermal Power with CCS

Title: D5.1 Plant Operating Cost Modelling

Abstract:

This report and its attachments consider how a large scale gas with CCS plant might operate in a future energy system and provides detailed estimates of both fixed and variable operating costs. Cost are built ‘bottom up’, considering likely staffing requirements, required maintenance schedules etc. As was expected, variable costs are dominated by fuel costs. The major fixed cost items are insurance, staffing and maintenance.

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.

Detailed Report: Plant Operating Cost Modelling

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Executive Summary

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 CO_2 reduction targets: without CCS the energy system cost in 2050 could be £30bn per annum higher.

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. The work carried out on this project as described in this report involves developing an outline scheme and 'template' power plant design (Combined Cycle Gas Turbine (CCGT) with post combustion capture) and identifying how this might be built and operated at selected sites around the UK.

In summary, 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 has been achieved by bringing together best available design information and benchmarking data for such a Scheme.

SNC-Lavalin has developed a template plant design and a capital cost estimate for a large-scale deployment of CCGT + CCS for the UK. SNC-Lavalin has been supported by AECOM who have identified potential site locations for such a plant and the University of Sheffield who have supported the project with technical and policy expertise (please refer to the Detailed Report - Plant Performance and Capital Cost Estimating, ETI reference D4.1, SNC-Lavalin reference 181869-0001-T-EM-REP-AAA-00-00004 for the design and capital cost estimate).

This report provides an operating cost estimate for a generic plant design at a range of plant sizes deployed in a number of regions in the UK.[1] The report includes abandonment costs at the end of the life of the facilities.

The base design for a large-scale deployment of CCGT + CCS for the UK would be a 5-train plant exporting approximately 3 GW after losses.

Operation

The work undertaken by the project shows that the complexity of the CCS chain from CCGT flue gases, through carbon capture, compression, CO_2 transportation and injection makes frequent

[1] The report does not cover revenues or Levelised Cost of Electricity (LCOE).

starting and stopping of the plant challenging, so that a CCGT+CCS scheme would be best suited to baseload or high load factor operation. Restarting once the capture plant has cooled and/or injection stopped could take many hours, meaning that operation of the plant for ‘two-shifting’ and ‘peaking’ operation would be impractical.

Maintenance

The maintenance schedule is set by the intervals required for the CCGT equipment: the remainder of the chain would fit in with these maintenance intervals.

It is recommended that the whole onshore plant be shutdown and depressurised for major maintenance / turnarounds such that the larger population on site required for these activities is not exposed to the CO_2 hazard from the high pressure areas of the plant.

Annual OPEX Costs

OPEX costs vary year on year depending on the amount of operation and the maintenance tasks that are scheduled.

The OPEX costs are dominated by the fuel gas costs: approximately 65% of total OPEX costs are fuel gas at 50.1p/therm. A sensitivity analysis has been carried out to see what the impact of variations in fuel price will have because of large proportion this single item is of the estimate. +/- 10p/therm has a +/- 13% impact on the overall operating costs.

Insurance costs dominate the fixed cost estimate.

The maintenance costs are dominated by the offshore maintenance for which the 4D seismic survey (part of the MMV) is the largest component.

Costs have been estimate for hot, warm, and cold starts which show that there is a significant cost for cold starts because of the time taken from the start of the CCGTs before export of CO_2 can recommence. Assuming that revenue cannot be earned against a CfD until the plant has reached abated operation each cold start will cost approximately £0.5M. This reinforces that a mode of operation with frequent stops and starts is not preferred to baseload operation.

Regions

Separate models have not been generated to detail the regional differences between the selected sites. Some small variations may exist in staffing cost, wholesale towns water cost, or wayleave cost; however, these are not of significance to the overall cost model. For example, a decrease of 5% in labour costs would represent only a 0.19% impact on overall OPEX (single train).

Costs for the North East regions increase for 4 and 5 trains due to the addition of the second offshore platform, as do costs for Scotland beyond 1 train. Additional consumable costs of £510,000 per year as well as additional maintenance for well washing and additional monitoring costs would be included.

Increased electrical costs for the offshore heating and chiller required in the Northwest region, and the shoreline booster and compression stations for the Scotland region are considered as parasitic load and thus not reflected in the absolute operating costs. These factors are captured in the nominal output per region, discussed in the Detailed Report: Plant Performance and Capital Cost Estimating, document reference 181869-0001-T-EM-REP-AAA-00-00004 (ETI Ref: D4.1).

Transmisison costs vary between regions as well, from £7.12/kW for North-eastern England, £2.76/kW for Yorkshire/Humber, £1.13/kW for North Midlands, and £24.61/kW in North Scotland. For the OPEX estimate, £7/kW was used (National Grid, 2017) .

Number of Trains

The OPEX model produced by the project team shows that OPEX per kW is not a strong function of plant size, though there is some reduction due to staffing optimisation for multiple units, one offshore platform servicing multiple trains, and economies of scale in administrative costs: this is shown in the following table. This table is based on a north east England location.

OPEX Costs	1 Train	2 Train	3 Train	4 Train	5 Train
£ / kW	£417	£390	£382	£381	£377
£ / MWhr	£50	£47	£46	£46	£45

Table 1 – OPEX Estimate per kW – Year 4

Abandonment

The decommissioning and abandonment costs (ABEX) have been estimated. These show that the abandonment costs for the Northwest/North Wales region is lower than the North East of England regions because the maximum plant size is smaller (3 trains compared to 5) and because there is only one offshore facility to abandon compared to two platforms for 4 or 5 train size plant over the Endurance Aquifer.

Scotland has the highest cost, due primarily to the cost of abandoning two offshore platforms which are installed in deeper water than other regions. It also includes the abandonment of the existing 198 km Feeder 10 pipeline.

Offshore pipelines have been estimated using data from Oil and Gas's 2013 "Decommissioning Pipelines in the North Sea" and Offshore Magazine, and assuming that the lines will be flushed, cut, and lifted (Oil & Gas UK, 2013), (Borwell, 2014).

No. Trains	5 Trains	5 Trains	5 Trains	3 Trains	3 Trains
Area	**Teesside**	**North Humber**	**South Humber**	**Northwest / North Wales**	**Scotland**
Total Cost (£m)	£270	£267	£267	£131	£251

Table 2 – Abandonment Cost per Region

1 Structure of Report

This report describes the approach taken to develop an operating cost estimate for the Generic Business Case design.

Section 3 provides an overview of the CCGT + CCS Scheme.

Section 4 explains the operation and maintenance philosophy developed for the CCGT + CCS Scheme.

Section 5 investigates the potential operating scenarios for the CCGT + CCS Scheme, which are viable for the Scheme design, and what has been selected for the operational modelling.

Section 6 provides the basis for the Estimate.

Section 7 explains the methodology used for the Estimate and Section 8 lists the assumptions used in its creation.

Section 9 presents the OPEX Estimate which can be seen in Attachment 8.

Section 10 presents the ABEX Estimate

Section 11 benchmarks the OPEX Estimate to ensure the robustness of the outcome of the estimating work.

Section 12 presents the hazards for operations and maintenance noted during the creation of this report in order to communicate them to those who wish to develop this work and to explain where HSSE aspects have impacted the cost estimates.

Conclusions and recommendations from the work are presented in Section 13.

2 Introduction

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 CO_2 reduction targets[2]: without CCS the energy system cost in 2050 could be £30bn per annum higher.

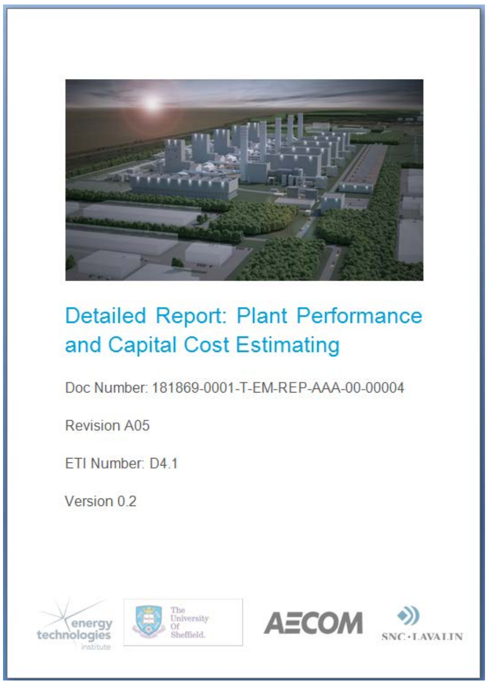
With planned retirements of the UK's existing fossil fuel and nuclear fleet, there will be a growing need for new, dispatchable power through the 2020s, with low CO_2 intensity to meet tightening carbon budgets.

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. Therefore, as noted above, the ETI has identified a need to develop a clear vision of what a cost-effective gas power with CCS scheme might look like and provide a clear and credible performance and cost information for such a scheme. To achieve this, the project as described in this report involves developing an outline scheme and 'template' power plant design (CCGT with post combustion capture) and identifying how this might be built and operated at selected sites around the UK.

In summary, 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 has been achieved by bringing together best available design information and benchmarking data for such a Scheme.

SNC-Lavalin has developed a template plant design and a capital cost estimate for a large scale deployment of CCGT + CCS for the UK. SNC-Lavalin has been supported by AECOM who have identified potential site locations for such a plant and the University of Sheffield who have supported the project with technical and policy expertise.

[2] 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."


Detailed Report: Plant Performance and Capital Cost Estimating

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Version 0.2

Figure 1 – CAPEX Report

The plant design and capital cost estimate in included in the Detailed Report: Plant Performance and Capital Cost Estimating, document reference 181869-0001-T-EM-REP-AAA-00-00004 (ETI Ref: D4.1).

This report uses the design information from the Plant Performance and Capital Cost Estimating report to provide an operation (OPEX) and abandonment (ABEX) cost estimate for the generic plant design at a range of plant sizes deployed in a number of regions in the UK. This report does not cover revenue or the Levelised Cost of Electricity (LCOE).

Life of Plant

The design life of the plant is specified in the Template Plant Specification, doc ref: 181869-0001-T-EM-SPE-AAA-00-00001 (ETI project deliverable D2.1).

The economic life considered for the plant is 15 years: this would align with a revenue mechanism for a CCGT + CCS scheme (such as CfD). It can be expected that additional investment may be required after 15 years of operation such as the drilling of additional injection wells, replacement of repurposed infrastructure, or installation of additional injection platforms, and that this future investment is not included in this report.

This report includes OPEX figures for 25 years which is the design life for the onshore facilities.

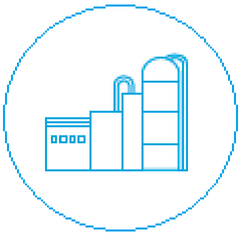
3 CCGT + CCS Scheme

The Generic Base Case scheme consists of the following:

Power Generation Station

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.

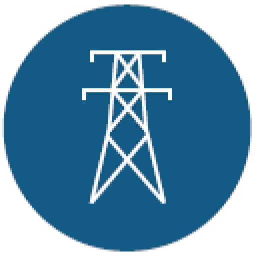
The electrical power is exported to the UK National Grid from where is serves the needs of industry, commerce, and domestic homes.



Carbon Capture and Compression

The carbon capture plant uses an amine solvent 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.



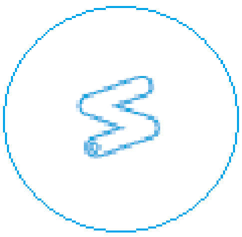
Connections:

- Electrical Power Export
- Natural Gas Fuel
- Make Up Water

The electrical power is exported to the UK National Grid via an over head line from where is serves the needs of industry, commerce, and domestic homes.

Natural gas fuel is brought in from the national grid by pipeline for use in the gas turbines.

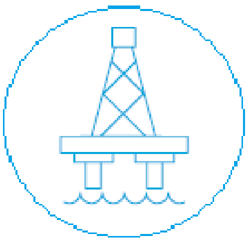
Make up water is brought into the plant to make up for evaporation and drift losses from the cooling towers on the plant.



CO_2 Transportation

- Onshore Pipeline
- Subsea Pipeline
- Above Ground Installations

CO_2 is transferred by pipeline from the carbon capture plant to the offshore store. If the onshore pipeline is of extended length then block valve stations will be required in order to safely isolate sections of the pipeline. (A booster station will also be required for a Southern Scotland location in order to boost the pressure of the CO_2 before sending offshore.)



Offshore Storage

CO_2 is stored in an underground saline aquifer or depleted gas field deep under the seabed. Injection wells will be drilled to allow the CO_2 to flow into the underground store.

The wellheads will be installed on an offshore platform.

4 O&M Philosophy

The operation and maintenance (O&M) philosophy for the CCGT + CCS Scheme is summarised in the following:

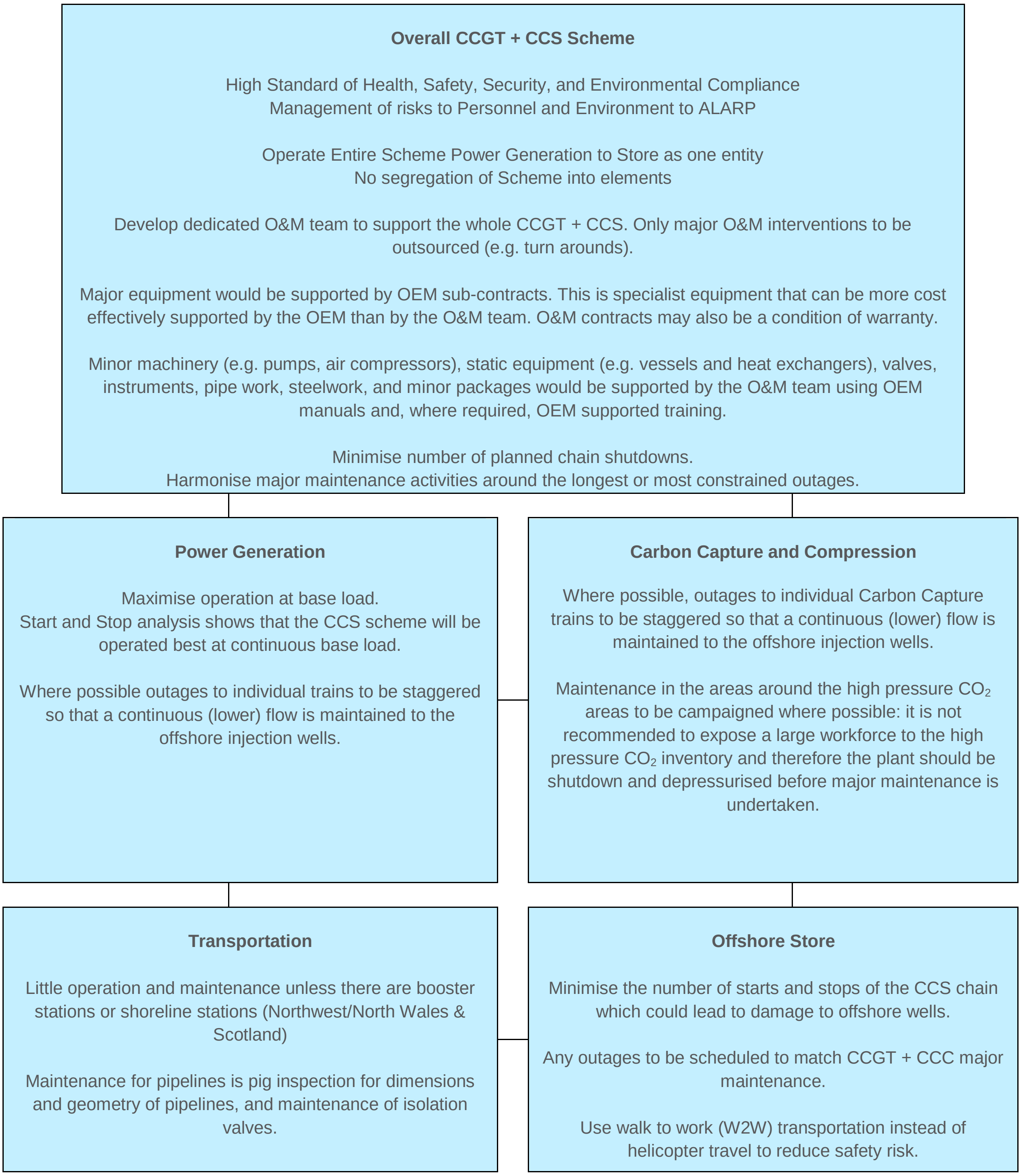


Figure 2 – O&M Philosophy

This section describes how the different elements of the CCGT + CCS scheme are assumed to operate and how they are maintained.

4.1 Power Generation

Operation

The Power Generation facilities are expected to operate at base load or high load factors with the number of starts and stops minimised. The CCS chain does not operate well in cyclic or start / stop operation. This does limit the flexibility of a Thermal Power with CCS scheme. However, the scheme has sufficient flexibility to operate alongside nuclear and offshore wind generation, and to be switched off ahead of these generation sources should generation exceed demand.

The GBC scheme is designed to have up to 5 trains of CCGT + CCC. For plants where there are multiple trains there is ‘chunky’ flexibility available in that individual trains can be switched off whilst still generating power and capturing CO_2 which is injected into the store. ‘Chunky’ flexibility has the advantage that CO_2 is flowing to the injection wells so that they do not have to be closed in.

The design of each train allows it to be turned down. The turndown performance is provided in Attachment 4 to the Detailed Report: Plant Performance and Capital Cost Estimating, document reference 181869-0001-T-EM-REP-AAA-00-00004 (ETI Ref: D4.1).

Maintenance

CCGTs are designed to minimise maintenance downtime in order to reduce the amount of time the plant is not delivering electricity.

It is assumed that the maintenance schedule for the CCGTs will dictate the maintenance schedule for the rest of the CCGT + CCS chain. This is because, with the exception of corrosion, the CCGT operating conditions of combustion, Rankine Cycle, and operating speeds, would tend to be more arduous than those in the process plant: corrosion in the amine and CO_2 systems would be managed by correct material selection (e.g. 316 Stainless Steel). The CCGT maintenance intervals are tightly specified by the OEMs for the equipment and are usually tied to warranty conditions. The maintenance intervals for the remainder of the scheme (CCS) would align to the scheduled maintenance regime for the CCGTs. API Standards used for Process Equipment tend to specify continuous run times of 3 years which would align with the first major CCGT outage for the Gas Turbine Hot Gas Path Inspection: this would include the 3 year internal inspection of the CO_2 Compressor as shown on the maintenance schedule in Attachment 2. The replacement of the molecular sieve in the dehydration unit would also align to a 3 year run time. Process unit shutdowns / turnarounds at 6 year intervals (Pilling, 2016) would tend to align with the major overhaul of the Gas Turbines.

Please note that the inspection and maintenance intervals for an actual CCGT + CCS scheme should be ascertained by a Competent Person based on the final design, operating conditions, risk assessments, etc, in accordance with UK Regulations such as the Pressure Systems Safety Regulations.

4.2 Carbon Capture and Compression

Operation

The carbon capture units will start-up after the CCGT units once stable flue gas is available. If the carbon capture units are cold then the steam lines to the amine reboilers will need to be warmed and the amine solvent will need to be heated. The steam lines are warmed by admitting steam to the headers. Experience from other plants is that it can take a shift to warm the steam headers sufficiently for operation. Whilst the steam headers are being warmed the amine solvent in the plant will be circulated. The amine solvent will be heated to a target temperature around 60°C after the steam lines are warm and steam is charged to the plant. It is important to note that utilities like cooling water should be circulating through the plant exchangers before heating the amine.

Operation for carbon capture will begin with the direct contact cooler (DCC) being brought on line, all wash loops beginning to be circulated, the booster fan being started, and the stack damper position changed to allow flue gas flow to the carbon capture unit. Once the carbon capture plant is started CO_2 will begin to be generated from the CO_2 stripper. The CO_2 will initially be vented from the top of the Stripper until the CO_2 meets the required specification when venting will be stopped and the CO_2 will begin to flow to the compression.

The compression system will begin operation. The compressed CO_2 will be dried through the dehydration unit. The compressed CO_2 will be vented until it meets the specification when it will be sent to the pipeline.

For a hot start it is assumed that the temperature will be maintained within the amine solvent circuit as the system is insulated for heat conservation and that the CO_2 compression and dehydration can be maintained in a pressured and warm condition: the carbon capture and the CO_2 compression can be rapidly restarted in this scenario. For very short shut downs (e.g. trips in carbon capture or pipeline system) the plant operators may opt to keep the compression system in recycle so as to restore operation more rapidly.

There will be heat loss from the carbon capture, CO_2 compression, and dehydration systems over time: for a warm start this will require some heating of the amine solvent circuit before commencing operation. The CO_2 compression and dehydration will require a period of operation and venting in order to get the compressed CO_2 to a suitable specification for the pipeline.

The cold start described above will be required if the plant is allowed to cool: experience is that this will take around a shift (10 hours). Once the plant is cool the circulation of the amine solvent will cease as the viscosity of the amine solvent increases and requires additional energy to pump around the circuit. The compression and dehydration system will be blown down in order to prevent the formation of condensation.

Maintenance

The maintenance regime for the Carbon Capture and Compression Units will be dictated by the CCGTs.

A HAZID was carried out for the plant (outside of original scope for the project). The HAZID has reinforced that a large maintenance population should not be exposed to the CO_2 hazard. To eliminate CO_2 hazard from high pressure CO_2 it is recommended that the shutdown maintenance for the CCGT+CCS plant be campaigned as a complete plant shutdown. This will need significant planning, OEM, and O&M Contract personnel on site. Maintenance would be carried out with little or no high pressure CO_2 on site.

4.3 Transportation

Operation

In this project it has been assumed that the transmission and storage system is dedicated to CCGT and CCC. Therefore no nomination system is included for taking CO_2 from a number of different sources into a pipeline and storage system. Also, as a result of dedicating the Transmission and Storage system to the GBC project, the only CO_2 quality measurement is at the CCC plant: it is assumed that if the CO_2 enters the pipeline and storage system within specification there is not a source of contamination that would alter the composition before reaching the store.

The transmission and storage system is operated by remotely controlled isolation valves. Capacity control into the Transmission system is on the CO_2 compressors which use a combination of inlet guide vane and recycle to alter the amount of CO_2 being fed forward.

Maintenance

The CO_2 specification for the pipeline is dry with low oxygen levels in order to control the internal corrosion. The outside of the pipeline is coated and provided with regular anodes in order to control the external corrosion. These measures are designed to reduce the level of maintenance required over the design life of the pipelines.

The pipelines will be regularly pigged to ensure the cleanliness of the pipeline and to carry out inspection of bore and geometry of the pipelines.

The isolation valves along the pipeline will need annual maintenance to ensure that they are able to function when called upon to operate. Main isolation valves will have installed bypasses so as to have minimal impact on flows and pressures when the main isolation valve is closed for maintenance.

4.4 Offshore Store

Operation

The offshore facilities are unmanned and are designed to be controlled remotely from the Control Room within the onshore plant.

The aim of operation is to keep the injection wells in continuous and stable operation. Regular shut off of the wells is undesirable as it will result in repeated pressure and temperature cycling. It is assumed that during shut off the formation water will be able to seep back into the injection zone increasing the risk of Halite formation. Halite formation and cycling of the wells will increase the risk of damage.

Line pack[3] from the CO_2 pipeline would be used to continue injection should the production of CO_2 from the CCGT + CCS plant cease. The flow to the CO_2 injection wells would be reduced to a minimum in order to allow the longest possible duration of flow from line pack in order to extend the time before the injection wells have to be shut in.

Flow management into the injection wells is by motorised choke valves.

[3] The mass that a volume can contain is a function of the pressure applied to the volume: the higher the pressure the higher the mass of gas in the volume. Line pack is where the pressure of a pipeline system is adjusted to store or deliver mass in order to manage, wherever possible, transients and abnormal conditions in supply or delivery.

Maintenance

The facilities on the platform are to be minimised in order to reduce the amount of maintenance required to the bare minimum.

Routine maintenance visits need to be planned for the offshore facilities. Water washing of the injection wells is likely to dictate the frequency of maintenance visits. It is assumed that the CO_2 wells will need to be water washed once per annum to prevent halite formation in the wells from blocking pores in the aquifer / depleted reservoir which would inhibit CO_2 injection. The rate of halite formation will be a function of the aquifer / depleted reservoir chemistry and will vary from CO_2 store to CO_2 store. It is expected that the Endurance Aquifer will need more water washing than the other CO_2 stores selected for the GBC.

Water washing of each injection well is likely to take a number of days. It is therefore assumed that only one well will be washed on each maintenance visit. It is therefore assumed for a platform with three operating wells and one spare that at least four visits will be required per annum.

The O&M team visiting the offshore facilities will be transported by walk to work (W2W) vessel: as described in the Detailed Report: Plant Performance and Capital Cost Estimating, document reference 181869-0001-T-EM-REP-AAA-00-00004 (ETI Ref: D4.1), this is viewed as a lower risk substitution for travel by helicopter.

A Temporary Safe Refuge (TSR) 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 W2W landing and the survival craft. The TSR is to comply with UK offshore safety regulations.

4.5 Onshore Utilities and Facilities

Operation

Essential utilities such as fire water, emergency power generation, Low Voltage (LV) power, and compressed air must be in operation at all times except complete shutdown.

Utilities such as Natural Gas, Cooling Water and Demineralised Water must be available before the plant is started and will be running during operation of the plant.

Maintenance

Routing maintenance will take place as scheduled. For example, it is typical to test emergency generators and fire water pumps on a weekly basis to ensure they are functional should they be called upon.

The scheduled maintenance periods for the utilities should align with the CCGT maintenance schedule.

4.6 Whole Scheme

Operation

The key operations of the plant are start up and shut down. The start up sequence for the plant can be seen in Attachment 5 to this report.

> There are different conditions from which the plant can be started which are used in the Attachments:
>
> Cold Start (> 16 hours from shutdown) – the plant is started from a period of prolonged shut down or the initial start of the plant. Systems are shut down and cold. Whole plant needs to be started up in sequence with each section / system being run up. Systems that need to run at temperature will take time to heat up from cold to operational either because of thermal inertia or because of potential to damage components by the thermal stress of increasing temperature too rapidly.
>
> Warm Start (6 – 16 hours from shutdown) – the plant retains some heat and the auxiliary and utility systems are in operation. Turbines would be rotated with barring gear. However, the equipment and systems on the plant are cooling so will take longer to bring up to temperature.
>
> Hot Start (< 6 hours) – the plant is still warm from recent operation and can be started more rapidly. The turbines on the plant would still be hot from previous operation and would be rotated with barring gear. The engineered amine solvent within the carbon capture unit would still be warm from operation. Steam lines around the plant would still retain heat from previous operation and the CO_2 system would remain pressurised.

START-UP

The start up sequence has been developed from experience of the project team and the references in Attachment 5. The timings for the start up are also shown in Attachment 5. There is a significant increase in the time to start the plant from a Hot Start to a Cold Start. For a cold start it takes roughly 24 hours to start the whole CCGT + CCS chain before starting to inject CO_2 into the store.

For a Hot Start the systems through the chain can be considered to remain at process operating temperature and pressure due to the short time since the CCGT + CCS scheme was stopped. This allows for rapid restart of the gas turbine. Once the gas turbine is started heat becomes available in the HRSG because of the hot exhaust gases leaving the turbine. Heat from the HRSG will maintain a production of steam which will allow for restart of the steam turbine. Once the CCGT power generation station has been started there will be a steam supply available from the extraction of the steam turbine. Steam is required in the carbon capture unit to maintain temperature of the engineered amine solvent: the solvent has a lower viscosity at temperature which aids pumping around the amine solvent circuit and the amine is better at absorbing CO_2 from the turbine flue gases at temperature. Steam is mainly required for the reboilers that serve the strippers providing the heat to separate CO_2 from the engineered amine solvent. Once the carbon capture unit is receiving steam from the CCGT power generation station then flue gas can be admitted to the carbon capture unit. This will require the booster fan to be started in order to draw flue gas into the direct contact cooler and the absorber. Once CO_2 is being captured by the engineered amine and produced in the stripper column it can be fed forward to the CO_2 compression and dehydration. There will be a delay in the compression unit whilst the CO_2 is processed to meet the pipeline specification as it is assumed that there will be a mixing of dry and wet CO_2 during settle out and that it will take a short time for the CO_2 passing through the dehydration unit to be dry enough for admission to the pipeline. For a short period until the CO_2 meets the pipeline specification it will be safely vented. Once the CO_2 meets the required specification it will be admitted to the pipeline: only at this stage will the chain be capturing CO_2 approximately 2 to 2.5 hours after hot start has commenced. During this time the injection wells would be operating at minimum flow fed by line pack as discussed in section 4.4.

A warm start will take longer as the systems in the CCGT + CCS scheme will have lost some heat during the time that it is shut down. It will take time for machines to be brought up to temperature before being loaded in order not to exceed thermal stress limits. The amine in the carbon capture unit will take a short period to heat up. Some of the systems may need to have condensation drained before start up or run in recycle to get to satisfactory operating conditions before operation: this may take up to 6 hours for a warm start.

A cold start will take much longer than a hot or warm start:

- The CCGT machinery operates at high pressures and temperatures. The temperatures and pressures must be increased slowly to operational conditions so as not to exceed allowable stresses within the equipment.
- There is a large thermal inertia within the amine system. Once cool, it will take many hours to reheat the amine circuit back up to operational conditions. Heat is supplied through steam extracted from the steam turbine which is only available once the CCGT power generation station is in operation.
- The steam lines providing steam from the CCGT power generation station to the carbon capture unit must be blown before they can be used in order not to thermally stress the pipe work and to remove condensate.
- It is assumed that the CO_2 systems would be blown down for a cold start: this would be to limit the amount of condensation forming in the CO_2 systems as they cool: wet CO_2 conditions should be avoided as they tend to cause corrosion. Also, condensation in the CO_2 system may be cause damage to compression machinery and equipment. The CO_2 compression system will require draining of condensate, purging, and re-pressurisation before being brought back into service.
- The injection wells will be shut in during the shutdown. The injection wells must be restarted in a controlled manner to prevent any sub-surface damage.

It could take approximately 24 hours for the whole CCGT + CCS chain to be operational before starting to inject CO_2 into the store from a cold start. CO_2 would be safely vented from the time that the carbon capture amine system is producing CO_2 to the time that the compression system can feed CO_2 at specification to the pipeline. It is assumed that the pipeline would be pressurised (line packed) whilst the injection wells were brought on line so that CO_2 would not require venting during this period.

OPERATION

Different operating modes for the Scheme were investigated by the project which can be seen in Attachment 6.

The start up of the CCGT and CCS scheme will generate CO_2 which cannot be abated as it will take time from the start of the gas turbine with the production of CO_2 to the full operation of the CCS scheme to capture and store the CO_2. The longer the start the larger the amount of CO_2 that will be produced: a hot start will emit a lot less CO_2 to atmosphere than a cold start.

It is possible for the CCGT power generation station to operate unabated. Whilst this is not the design intent it is a requirement to allow the start-up of the overall scheme and to allow continued generation of power should the CCS not be in operation (e.g. due to a fault).

The CO_2 release to atmosphere during start-up operations is included in Table 7 – Carbon Capture Rate.

The CCGT + CCS scheme is capable of turndown. The gas turbines are capable of turn down to 40%: this does not equate to a 40% reduction in output power from the CCGT as the efficiency of the turbine drops at turndown therefore releasing more heat for the power output, which in turn means that there is more than 40% heat recovery for steam turbine power generation. The resulting turndown is to around 50% output.

There is the potential to have the plant operating at no load, with machinery unloaded, and systems in recycle. This is very wasteful of energy (and cost for natural gas) and therefore it is unlikely that this mode would be sustained for long periods. Also, as there is insufficient heat recovery there will not be enough steam to keep the steam turbine in operation: this will also cut off the steam heating to the amine solvent circuit.

SHUTDOWN

The shut down sequence of the plant can be seen in Attachment 7 of this report.

The subsection above on shutdown shows that there is a big difference in the time taken to restart a CCGT + CCS chain from a cold condition compared to a hot condition.

For a short shutdown it is assumed that the majority of systems would be maintained in an unloaded condition or recycle in order to be ready to restart as quickly as possible. Once the plant is unloaded there will not be sufficient heat recovered from the gas turbine to provide steam to the steam turbine and therefore this will have to be shut down. Should the plant be unloaded for more than a short period (~10 minutes) the gas turbine and compression will be shutdown so as to reduce the utility and parasitic energy consumption on the plant. Once the gas turbine is shutdown then the flue gas path will require to be purged before restart so as to ensure that an explosive mixture has not formed before the gas turbine combustors are relit.

Two hours is allowed before the wells have to be shut in: this is the amount of time that the line pack will provide forward flow to the wells when the flow rate is reduced to minimum.

A further 10 hours is allowed for the amine unit and compression: this is based on experience of how long the plant will take to cool down. Once the amine has cooled down it will need to be brought up to temperature again before operation can resume. Heat will need to be supplied by steam. Once the steam mains have cooled they will need to be brought back up to temperature again. There is a risk of water condensing in the inlet section to the compressors: once the wet CO_2 section is cooling the system will need to be blown down to prevent condensation forming in the system.

If the amine circulation in the carbon capture units has been stopped and the CO_2 compression system has been shut down then the major utilities are no longer required and can themselves be shut down to reduced energy consumption from the plant.

If a prolonged shutdown is necessary because power generation is not required by the grid then all non-essential utilities can be shut down in order to reduce energy consumption from the plant. The plant isolations should be carried out to ensure the facilities are left in a safe condition during the shutdown and any immediate preservation work should be carried out so that equipment does not deteriorate. A period without operation could be used to carry out any maintenance activities to reduce time required for outages when there is a requirement for power generation.

Maintenance

The maintenance regime for the plant can be seen in Attachment 2. The maintenance routine has been developed from experience of the project team and the references in the Attachment.

Maintenance intervention is carried out on a regular basis in order to maximise the availability of the plant whilst minimising the cost of the maintenance itself and minimising the downtime when the plant cannot generate revenue. Maintenance Routines are typically developed by equipment manufacturers and plant owners. The Maintenance Routine in Attachment 2 aims to show the significant maintenance interventions (those that entail significant cost and outage of the plant / scheme).

Maintenance routines tend to follow a cycle as interventions are usually required after a number of operating hours or a time duration. The frequency of interventions has been estimated assuming baseload operation. Where interventions are planned on different areas of the scheme around the same time interval the maintenance is planned to be carried out in parallel in order to minimise the overall downtime of the plant / scheme.

5 Plant Operating Scenario Basis

5.1 Potential Operating Scenarios

Baseload

Base load plants are power generation plants that supply a consistent and dependable amount of electricity to meet the minimum electrical demand of a power distribution system. The economic design of baseload plants is to maximise efficiency (thus minimising the fuel costs) in order to generate as competitively as possible.

Base load plants operate at maximum output and shut down or reduce power only to perform maintenance or repair.

High Load Factor

In a high load factor scenario it is assumed that power generation from a CCGT + CCS scheme is dispatched ahead of most generation sources because of its abated design but is shut down ahead of nuclear and wind power generation in meeting the power generation demand from the grid.

Two Shifter

2 shifter operation plants operate during the day and early evening.

2 shifter operation plants either shut down or greatly curtail output during the night and early morning when the demand for electricity is the lowest.

Hence 2 shifter – day shift generating and off at night.

Peaker

Peaker operation plants are power generation plants that run only when there is a high demand for electricity (peak demand). The power generated by peaker operation commands a much higher price per kilowatt hour than base load power because it is required on an occasional basis. Peaker operation plants are dispatched in combination with base load power plants.

Review of Operating Modes

The analysis of the high level start, standby, and shutdown sequences for the CCGT + CCS chain show that there is a penalty for frequent stops and starts. This is a direct result of the time taken to get the CCS scheme from cold to successfully injecting CO_2 into the store (please refer to Attachment 5 and 6 of this report).

The Shell Peterhead project estimated that there is around 2 hours of line pack[4] which would allow the wells to continue injecting at minimum turndown flow (Shell UK Limited, 2016); after which time the wells would have to be shut in. In sequence, the carbon capture and compression plant cools without the steam extraction from the Steam Turbine: the amine solvent viscosity increases as it cools which increases the power required to pump it around the circuit and increases wear and tear on pumps, valves, and filters. There will also be water condensation forming in the wet side of the CO_2 system from stripper to dehydration unit: any condensate must be drained before restarting the plant. After the duration of a shift (assume 10 hours) the amine circuit will require to be shut down and the CO_2 compressor system blown down (dry side CO_2 system from compressor discharge isolation valve would remain pressurised).

Without detailed operational modelling it would appear that the plant reaches shutdown status between 2 hours and one shift. It takes some time to restart the plant once it is shutdown. With this information it is clear that a drawback of peaker operation of frequent starts and short run times is that the plant would not be able to establish CO_2 sequestration in sufficient time to make an economic nor environmental case for carbon capture: there would be no advantage to attract a subsidy for CCS.

The 2 shifter operation would also not be advantageous because the plant would cool off overnight making a quick and efficient restart difficult.

Hypothetically a 2 shifter could be made to work if:

- Sufficient steam where supplied by an auxiliary boiler to keep the amine system warm during the shutdown periods (overnight).
- Sufficient heat maintained in wet side CO_2 system.
- There was sufficient line pack to keep minimum flow to the wells during the shutdown periods (overnight).

Keeping the system warm and CO_2 flowing to the wells would require significant energy and there would be a CO_2 penalty for each start and for the auxiliary boiler operation: philosophically the plant would not meet the primary objective of minimising CO_2 released to atmosphere.

The time taken to start the CCS Scheme is considerable (assumptions can be seen in the Attachments developed for the OPEX Report). The CCS Scheme will not respond well to frequent starts and stops as it is unlikely the entire CCS Scheme will be functional and storing CO_2 before the Power Plant is shut down again. It is therefore unlikely that CCS operation with a 2-Shifter or Peaker operation would be appropriate for the CCS plant. Therefore, the operation scenarios that make sense for the stable operation of the Thermal Power with CCS scheme are baseload or a high % load factor operation. The modelling undertaken by the ETI suggests 70% load factor operation as there are times when Wind and Nuclear would be dispatched ahead of a CCGT + CCS Scheme. It is an assumption that the scheme would be supported in this operation by a Contract for Difference (CfD).

[4] Line Pack is using pressure in a pipeline to store a mass of gas. Gas is compressible. The higher the pressure the more mass of gas can be stored in the internal volume of the pipeline. By letting down the pressure in the pipeline from a higher pressure to a lower pressure a mass of gas can flow forward from the pipeline.

An operating scenario selection should also consider that a CCGT + CCS scheme will be a relatively high CAPEX investment and such a plant running at lower load factors is unlikely to be economic.

Load Profiles

Load profiles of different scenarios for operation to be considered the Operational Cost Estimate:

	Baseload[5]	EHS	70% Load Factor	EHS	2 Shifter	EHS	Peaker	EHS
Starts								
Hot	5	5	5	5	5	5	5	5
Warm	4	20	14	70	208	1040	136	680
Cold	3	30	3	30	52	520	104	1040
Trips	2	30	2	30	2	30	2	30
EHS[6]		2125		3375		39875		43875
Operating Hours	7980		6132		3120		1080	

Table 3 – Potential Operating Scenarios

The operating model generated for the GBC will focus on base load / high Load Factor scenarios.

The table above calculates Equivalent Hot Starts (EHS). EHS is used by CCGT OEMs to measure the additional stresses placed on turbines by starts and trips: a higher measure of EHS will result in a decreased plant life and increased maintenance frequency compared to lower measures. The value of EHS increases with warm starts, colds starts, and trips as these place more stress on the machine than a hot start where the machine is at or near operating temperatures and pressures.

Though a slightly lower number of annual restarts was considered based on experience with prior CCS projects, the above operating scenario figures for CCGT plants from DECC were selected as a more conservative approach (DECC).

5.2 Performance

The revenue from electricity production is not covered in this report. However, the following performance is the basis for revenue modelling for the GBC and the performance is the basis of the OPEX modelling work performed.

Performance modelling is included in Attachment 4 to the Detailed Report: Plant Performance and Capital Cost Estimating, document reference 181869-0001-T-EM-REP-AAA-00-00004 (ETI Ref: D4.1) which contains both the 100% and 40% turndown cases. It should be noted that 40% turndown on the

[5] (DECC)
[6] Equivalent Hot Starts (EHS) over 25 Year Life

gas turbines does not produce 40% turndown on the overall CCGT plant: this is because the Gas Turbines efficiency drops at lower outputs resulting in a higher proportion of waste heat which is recovered in the HRSG and fed to the Gas Turbines. The following data is corrected to the 500 MW nominal gas turbine size.

The following is a summary of the technical performance of the designed Generic Business Case Plant.

Power Generation		
Item	**100% Clean / New Condition**	**Turndown Condition**
Gross	732 MW	354 MW
Efficiency @ Generator Terminals	62.0% (LHV)	55.5% (LHV)
Net (Gross minus Parasitic Loads)	715 MW	341 MW
Efficiency Net	60.6% (LHV)	53.4% (LHV)
Steam Abated (Gross Power with Abatement Steam Extracted)	691 MW	332 MW
CCGT Parasitic Electrical Load	17 MW	13 MW
CC Parasitic Electrical Load	52 MW	33 MW
Net Abated (Steam Abated minus CCGT & CC Parasitic Loads)	622 MW	286 MW
Carbon Capture & Compression		
Item	**Per Train**	Per Train
CO_2 Mass Flow	221 T/hr	119 T/hr

Table 4 – Summary of Technical Performance

The net output per train has been calculated for the sites selected for each of the regions. This output takes account of parasitic loads within the onshore CCGT + CCC plant, electrical loads for make up water pumping, and for transportation electrical loads (e.g. compression stations).

Region	Gross Output (MW)
Teesside	621
North Humber	621
South Humber	621
North West - Gas	623
North West - Liquid	621
Scotland	614[7]

Table 5 – Gross Output for Each Region

5.3 Availability

Plant availability is the percentage of time the plant is capable of generating saleable electricity to the grid. This is calculated using:

$$\text{Availability} = \frac{(8760 \text{ hours - planned outage hours - unplanned outage hours})}{8760 \text{ hours}} * 100\%$$

The time the plant is unavailable is made up of planned outage and forced outage components. The operating scenario in this example is based on continuous operation at full capacity apart from outages.

Planned outage time is calculated based on the routine maintenance schedule. It varies by year, and is determined by the scheduled maintenance requirements of each of the plant components. It is assumed that maintenance schedules will be dictated for the onshore equipment by the shutdown intervals required for the gas and steam turbines. Planned outage time has been detailed for each maintenance activity in Attachment 2. The planned outage factor per annum is based on the longest duration activity and assumed other maintenance activities are performed in parallel.

The forced outage factor represents the time a plant is out of service due to unplanned maintenance and repair. A forced outage factor was used based on a benchmarking study undertaken by ETD Consulting (Shibli, Akther, & Hampson, 2015). Though the forced outage factor in this study was based on cyclic operation, the low range has been assumed as a conservative estimate for a baseload plant.

Figure 3 below represents the planned and forced outage factors over the life of the plant shown as a % of total time the plant is out of service. The peaks in years 6, 12, 18, and 24 are due to a 49 day outage for a gas turbine major overhaul. During this annual outage time, all other plant maintenance requiring the plant to be out of service is performed. The slightly lower peaks in years 3, 9, 15, and 21 include outage time for major inspections.

[7] The Scotland region location reuses Feeder 10 for CO_2 transportation which requires an intermediate Compression Station but only to overcome the pressure drop for a 3 train scheme.

The forced outage factor decreases in the early years of the plant operation as initial performance problems are worked through. The plant reaches optimum reliability around Year 11, after a period of performance improvements, after which forced outages begin to increase slightly as the plant ages and fatigues. CCGT based data was chosen for overall availability and reliability figures as it is the overall driving factor for frequency and duration of maintenance activities. There is no direct link between the calculation of forced outages and the number of restarts per year. CCGT data was chosen in both instances, as it is considered to be more conservative. The forced outage factor is used to calculate plant availability, whilst the number of restarts is used to calculate a cost associated with planned and unplanned plant shutdowns during an operating year.

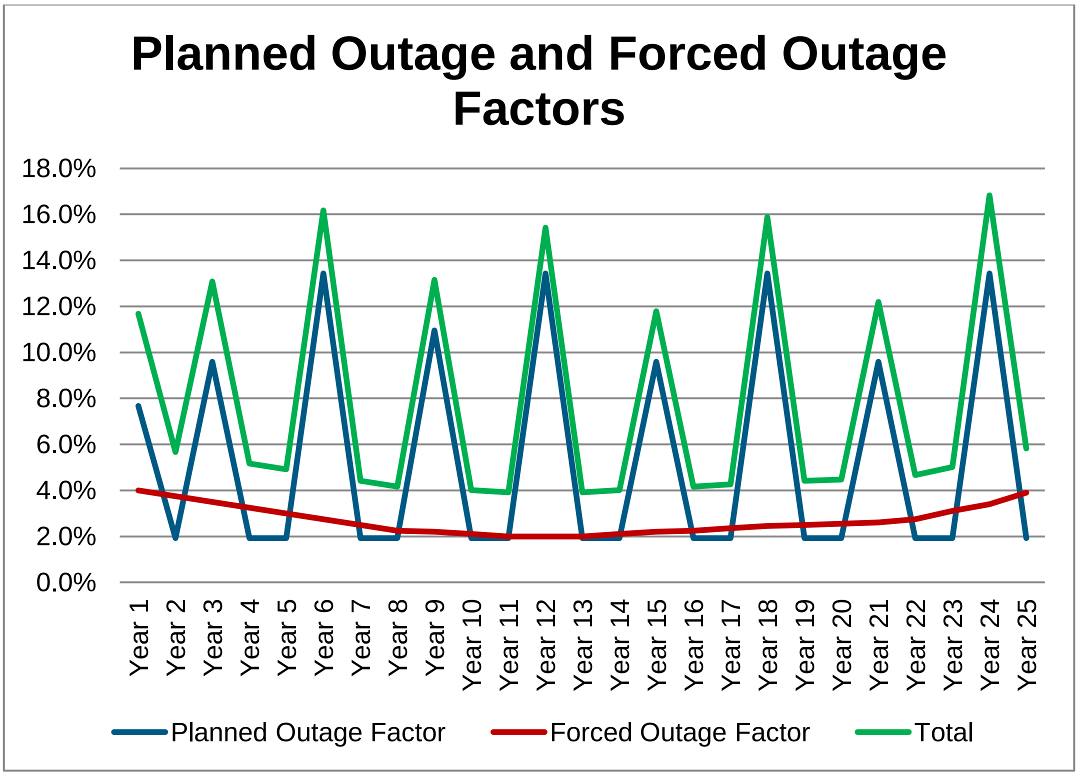


Figure 3 - Planned and Forced Outage Factors

5.4 Load Factors

Load Factor is the ratio between the actual energy generated by the plant to the MAXIMUM possible energy that can be generated with the plant working at its rated power and for a duration of an entire year. This is calculated using:

$$\text{Load Factor} = \frac{\text{MWhr generated in one year}}{\text{(Available Hours * Peak MWe Output)}} * 100\%$$

Base load operation against a CfD is anticipated and modelled for this report. Load factors can be adjusted within the model.

5.5 Number of Starts

The number of starts is given in Table 3 – Potential Operating Scenarios.

5.6 Capture Rates

The selected post combustion carbon capture technology specification for the GBC project is to recover 90% of the CO_2 in the flue gas. Current technology can be designed to achieve recovery rates higher than 90% in steady state base operation. For a particular plant improvements in amine formulation during its lifetime would be expected which would improve this recovery. However, this is not included in the current OPEX estimates. Current technology can achieve recovery rates higher than 90% in steady state base operation. Better amine formulation are expected to improve this recovery, however, this is not included in the current GBC design.

90% CO_2 recovery for the nominal turbine design will result in the following:

Per Train	Capture Rate (90%)	CO_2 Emission
100% Operation	221 T/hr	25 T/hr
Turndown	119 T/hr	13 T/hr
Unabated (Start-Up, etc)		246 T/hr
Shut-Down (Aux Boiler Running)		4.4 T/hr

Table 6 – Carbon Capture and Emissions

There is CO_2 which is produced during the starts of CCGT + CCS scheme as described in section 4. The amount of CO_2 captured is shown in the following table based on number of starts from Table 3 – Potential Operating Scenarios, base load operation, and the outage factors in Figure 3 - Planned and Forced Outage Factors.

Year	1	2	3	4	5	6	7	8	9	10
Capture Rate	88.7%	88.8%	88.7%	88.8%	88.8%	88.6%	88.8%	88.8%	88.7%	88.8%

Year	11	12	13	14	15	16	17	18	19	20
Capture Rate	88.8%	88.7%	88.8%	88.8%	88.7%	88.8%	88.8%	88.6%	88.8%	88.8%

Year	21	22	23	24	25
Capture Rate	88.7%	88.8%	88.8%	88.6%	88.8%

Table 7 – Carbon Capture Rate

6 Basis of Estimate

The Basis of Estimate for the Generic Business Case can be found in the Detailed Report: Plant Performance and Capital Cost Estimating, Attachment 10 (Document 181869-0001-T-EM-REP-AAA000-00004, ETI Reference D4.1). The basis of estimate supports the operating of the CCGT + CCC plant following start-up through its operating life. Commissioning and Start-up costs have been included in the CAPEX estimate in Detailed Report: Plant Performance and Capital Cost Estimating.

The estimate is based on the Association for the Advancement of Cost Engineering International guidelines for estimating, and follows the accepted criteria for a Class IV estimate. The Class IV estimate is used at the concept phase of a project and has an expected accuracy range of -15% to -30% and +20% to +50. The OPEX estimate may be considered analogous to a Class IV estimate as the methodologies and accuracy ranges are in keeping with the AACE estimating standards for this level. The key documents used for the preparation of the estimate were the Utilities Schedule, Operations Team organisation chart, Maintenance Routine, and O&M Subcontracts Schedule.

The OPEX cost estimate has been built up using a combination of vendor quotes from previous projects for similar materials, consumables, and subcontracts, maintenance costs, scaled up vendor pricing, and SNC-Lavalin cost estimating norms. SNC-Lavalin data has been used for staffing costs, administrative costs, and other elements as referenced in the OPEX model in Attachment 8. The estimates have been built up by plant section i.e.) CCGT and CCC, and have been benchmarked against a robust set of data compiled from prior project experience, previous proposals, industry published information, and publicly available data.

Fixed Costs

The following are fixed costs for the operation and maintenance of the CCGT + CCS Scheme, these will not vary with the MWhrs and CO_2 produced by the plant:

- Pre-start-up costs and handover from EPC Contractors;
- Staffing;
- Administration;
- Direct overheads;
- Maintenance;
- Well monitoring;
- Inspection and condition monitoring;
- Insurance;
- Local rates, taxes, insurance, utility tariffs;
- Decommissioning and handover to abandonment contractor.

Variable Costs

The following costs for the operation and maintenance of the CCGT + CCS Scheme will vary with the MWhrs and CO_2 produced by the plant:

- Fuel and utilities;
- Chemicals and Catalysts;

- Waste disposal;
- Emissions.

6.1 Pre-start-up costs and handover from EPC Contractors

The Operation and Maintenance team management and engineering functions would be created early in the project life cycle in order that the key members of the O&M team have an understanding of the plant design and can influence key decisions relating to how the Asset will be operated and maintained. The O&M team work during the design phase of the project will include dictating Operation and Maintenance Philosophies, specifying spares procurement, developing OEM maintenance support agreements, design for maximising plant availability and safe maintenance, attendance at HAZOPs and input into design reviews.

The O&M team would grow during the EPC phase of the project to allow for attendance of engineers and technicians at Factory inspections and Factory Acceptance Tests. Major equipment, package, and systems orders will include training for the O&M team including classroom, factory based, and on site practical activities.

Orders for Integrated Control and Safety System (ICSS) typically include a training simulator (although this can be contracted separately). Modern training simulators include a games console style simulation of the plant as well as of the operating systems allowing for both control room and field training of normal starts, stops, and operation, as well as response to trips, accidents, and emergency response. Simulator training allows the operations and maintenance staff to be familiarised with the plant before it is built.

Formal safety training, including offshore survival, will be required before the commissioning phases of the project. Typically, the O&M team will have an involvement in the acceptance of the plant, punching out before handover, and management of the close out of the EPC Contractors' punchlists. During the pre-commissioning phase of the project the O&M team would be brought up to full strength to begin taking over the plant for commissioning.

The cost of man power, training, and materials needs to be included in the O&M budget prior to the handover from the EPC Contractors and the start-up of the CCGT + CCS Scheme.

6.2 Staffing

Staffing has been built up from the organisation required to operate and maintain the whole CCGT + CCS Scheme.

This can be seen in Attachment 1.

The operations and maintenance team is built up on the following basis for any sized plant:

- Information available from publically available sources;
- A six shift pattern workforce for 24 hour a day operation. The calculation for a shift pattern for manning within the Working Time Directive limits of 48 hours maximum per week and 11 consecutive hours rest in any 24 hour period results in five shifts being required. An additional shift has been added for the plant in order to provide for an offshore team. It is planned that Operations and Maintenance personnel from the onshore plant be used to provide O&M teams for the offshore facilities: this is more expensive than a dedicated offshore team but provides the

members of the O&M team with a knowledge and vested interest in the performance of the entire CCS team fulfilling the business driver for the scheme.

- The number of personnel is based on a 5 train CCGT + CCS scheme. The number of personnel within the organisation has been adjusted within the operating cost model for 1 to 4 train sized CCGT + CCS schemes. Please refer to section 9.2 for further details of how the staffing level is adjusted for the number of trains.

There are alternatives to a direct hire O&M team:

- The O&M team could be subcontracted: there are a number of providers who could provide an O&M service contract to provide varying levels of support to the plant.
- Subcontract maintenance scope: again, there are a number of providers who could provide planned and call off maintenance services. This would be easier if the CCGT + CCC plant is located near or in a major industrial area where there is an abundance of necessary skills.
- There could be a dedicated O&M team for offshore or subcontracted offshore O&M team.

It was felt that a direct hire O&M team best meets the Business Driver of maximising reliability of the Thermal Power + CCS scheme because a CfD would only pay if CO_2 is successfully sequestered. There is not a significant difference in cost between the options: as long as the team size is correct then this should be suitable for the cost estimate.

Integrated Team

The O&M team is assumed to be integrated – i.e. covering Power Generation, Carbon Capture, Transport, and Offshore Storage. A major learning from previous CCS projects and studies is to develop a common culture for future CCS projects and not to allow a schism along junctures of the CCS chain from Power Generation, Carbon Capture and Compression, Transportation, and Offshore. For CCS to be successful the whole chain must operate together.

The developed shift pattern shall allow for O&M team members to work offshore. This will require a higher training budget than a dedicated offshore support team or outsourced offshore support team: however, will ensure that the O&M team have knowledge of and support the whole CCS chain. The outcome is intended to be a better availability because the O&M team has a better understanding as to how the entire scheme operates.

Executive and Management

The Executive level for the CCGT + CCS would represent the owner(s) of the scheme. An assumption was made in the Detailed Report: Plant Performance and Capital Cost Estimating, Doc Number: 181869-0001-T-EM-REP-AAA-00-00004 (ETI ref: D4.1), that the Owner would be a Special Purpose Investment Vehicle (SPV) with Investors coming from an O&G and Power background with potentially an OEM.

A Chairman would represent the Owner's interests, with a Managing Director in charge of the day to day running of the Scheme through a board of directors. Finance, Commercial, and Operations would be directly represented at the board level. A Company Secretary and two non-executive Directors would complete the board.

A management level would report to the Board of Directors.

Operations

Each shift consists of a Shift Superintendent, a Plant Engineer, 4 Operators, and an Apprentice Operator. The Operators will control the entire CCGT + CCS scheme (including offshore) from the control room. One operator would be dedicated to the power plant, one to the carbon capture and compression, one to the utilities, and one to the Transport & Storage.

The operations team would be supported on days by a Laboratory team, a performance team, and a HSSE team.

Reservoir Management Team (AAPG Wiki, 2014)

The Reservoir Management Team will be responsible for the CO_2 Injection and Store for the asset. They will liaise closely with the Commercial and Operations team for the Asset.

Job Title	Job Description
Reservoir Manager	Reservoir Manager will manage and coordinate the work of everyone in the subsurface team for the CO_2 store.
Injection Geologist	The Injection Geologist will be responsible for understanding and modeling the geological framework of the CO_2 storage reservoir. The Injection Geologist will help to identify and plan new well locations.
Geophysicist	The Geophysicist will interpret seismic data to define the CO_2 storage reservoir structure and fault distribution. Where the seismic data allows, depositional environments, and rock and fluid properties can also be characterised. This would be a part time technical consultant role.
Reservoir - Physicist	The Reservoir-Physicist will analyse wireline logs to quantify the rock and fluid properties of the reservoir / aquifer in each well location. This would be a part time technical consultant role.
Data Manager	The Data Managers provide technical support to the Reservoir Management Team, including data management, data preparation, data processing, and computer mapping.
Reservoir / Aquifer Engineer	Reservoir / Aquifer Engineer will use a computer simulation of reservoir / aquifer performance to predict the amount of CO_2 that can be injected and analyse how the store will behave. The Reservoir / Aquifer Engineer will take a lead in reservoir / aquifer management.

Injection Engineer	The Injection Engineer is responsible for optimising the mechanical aspects of CO_2 injection from the surface facilities to the wells.
Injection Chemist	The Injection Chemist will analyse and treat any problems related to scale formation, metal corrosion, drilling fluids, and solids precipitation between the storage reservoir / aquifer and the surface facilities.
Drilling / Work-over Manager	The Drilling / Work-over Manager will plan the mechanical aspects of any well operations, including drilling new wells, and will directly manage the offshore drilling contractor.
Drilling / Work-over Engineer	The Drilling / Work-over Engineer will design the mechanical aspects of any well operations including drilling new wells. The Drilling / Work-over Engineer is assumed to be part time for cost estimating: however, the actual work practice is likely to be periods of full time working when required for Drilling / Work-over activities followed by periods of inactivity when this work is not required,

Table 8 – Reservoir Management Team

Procurement

A Procurement Team has been provided to control the purchasing and storage of material, consumables, equipment, and spares for the operation and maintenance of the Scheme. The Procurement team will also arrange and manage sub-contracts for the Scheme such as waste disposal.

The Procurement team will also support the Quality Assurance and Quality Control functions within the Scheme: this is a core competence within the acquisition process for material and equipment: these functions will also serve other teams within the organisation.

Maintenance

A maintenance team will support the routine and emergency maintenance within the Scheme in order to maximise the availability of the Asset. Planned outages and turnarounds would be supported by an external O&M Sub-Contractor who would provide peak resourcing for these intense periods of work.

Function	Description
Engineers	A multidiscipline engineering team is provided to understand and technically manage the asset, supporting performance and condition monitoring of key components within the Scheme, specifying interventions, and interfacing with technical support from OEMs and O&M Subcontractors.

Function	Description
Technicians	Responsible for servicing and repairing equipment and systems in order to maximise the availability of the asset.
Maintenance Superintendent	Responsible for managing the day shift routine and emergency maintenance work within the Asset.
Maintenance Planners	The Maintenance Planners will work closely with the Engineers and the Commercial team to schedule maintenance which requires a partial or total plant outage. The planning work for outages will aim to maximise workfaces and resources in order to minimise the time during which the plant does not generate power (and revenue). Routine maintenance will also be planned by the team to ensure that the Asset is maintained in good working order and that any mandatory inspection intervals are met.
Crafts Team	The Asset will have its own set of crafts persons, labourers, and Apprentices who will be responsible for the routine and emergency maintenance tasks, and housekeeping within the PPE areas. Housekeeping of non PPE areas would be performed by contracted cleaning services.

Table 9 – Maintenance Team

6.3 Administration

The team for the operation of the plant includes administration personnel (please refer to Attachment 1). This is reflected in the cost estimate.

Administration services, such as Security and Cleaning, are included in the subcontract services estimate (please refer to Attachment 2).

Additional administration costs, such as IT hardware and software, office furniture rentals, and PPE, are included as fixed costs.

6.4 Direct overheads

Direct overheads are those which are not included under other descriptions and include:

- Accounting fees (e.g. independent audit of accounts);
- Recruitment (it is assumed that for the size of business recruitment would be outsourced);
- Interest on loans;
- Legal fees;

- Rent (assume that majority of land is acquired, however, will be rented land for pipeline wayleaves);
- Non-plant related repairs (e.g. buildings fabric);
- Stationary supplies and IT consumables (e.g. printer paper & printer cartridges);
- Travel expenses (e.g. for travel to training or meetings with OEMs).

6.5 Maintenance

Scheduled and unscheduled maintenance is required in order to keep the plant in good working order, to be able to meet the performance required, and to operate reliably.

A high level maintenance schedule has been developed for the plant (please refer to Attachment 2) which sets the rhythm and routine of maintenance intervention and shutdown for the plant. This schedule has been developed from Key Knowledge Documents (KKDs), referenced documents, and the knowledge of the project team.

Initial Inspection

The initial inspection is carried out after a short service period (bedding in) to allow tolerances with machinery to be optimised for reliable operation: typically this involves removal of generator rotors. It is assumed that this would be carried out by personnel from the OEM.

Minor Inspections

Minor / routine inspections are carried out on the exterior of equipment, plant, facilities, and connections. Whilst equipment and plant will be shut down and cool to touch, it is not planned for minor inspection to involve depressurisation, nor breaking of contained systems, or opening of equipment. Minor inspections will allow for adjustment / optimisation of control settings. It is assumed that the Scheme O&M team would carry out these inspections.

Major Inspections

Major inspections will require shutdown, depressurisation, and purging of systems to allow invasive inspection. Invasive inspection will allow access to internal components of plant or equipment through hand holes, man ways, and inspection ports (boroscope access). Major inspections will allow minor maintenance and modification work. It is assumed that the Scheme O&M team would carry out major inspection work with support from OEMs and sub-contractors. The overall scheme shutdown / turnaround would be managed and executed by a specialist contractor.

The major inspection of the pipelines (gas and CO_2) will be intelligent pig runs to monitor pipeline condition and thickness.

Interventions

It is assumed that each of the CO_2 injection wells will require water washing on an annual basis. The maintenance visits to offshore platforms are scheduled to coincide with the water washing regime with the assumption that one well would be washed on each visit. Water washing is intended to dissolve any halite formation, caused by interaction of CO_2 with salts in the aquifer / reservoir, which could block pores in the store and inhibit CO_2 injection.

Overhaul

Major overalls will require equipment to be opened up (i.e. tube bundles pulled, machinery casings opened). Typically wear parts are replaced (seals, bearing pads, etc). It is assumed that overhauls would be carried out by the scheme O&M team with support from OEM.

Major Machinery Maintenance Intervals

Major Machinery Overhauls are typically scheduled based on a number of 1000 operating hours.

Operating hours are calculated based on actual operating hours + operating hour allowance expenditure for starts. The expenditure for starts tends to proportional to the speed of start (slow / rapid) and working condition (e.g. hot / warm / cold) start.

6.6 Storage Measurement, Monitoring and Verification (MMV)

Measuring, Monitoring and Verification (MMV) activities are included in the Cost Estimate. These activities can be seen in Attachment 2.

The CO_2 storage sites proposed for the Thermal Power with CCS Project will need to be monitored to ensure that over the duration of the disposal operation and for a specified duration following abandonment, the injected CO_2 remains securely stored.

Monitoring information will be used in history-matched simulations to calibrate predicted behaviour (e.g. reservoir flow simulations of CO_2 migration) against real-time behaviour (e.g. 4D seismic images of the CO_2 plume) within the storage reservoir.

Leakage from the CO_2 stores is not expected because of robust reservoir / aquifer selection, well / injection design, and risk assessment / control / mitigation. However, MMV activities would provide the CCS Scheme Owner with information on CO_2 migration rates, volumes and timing expectations, that following unexpected leakage from a store would allow mitigation measures to be planned, designed, and implemented in the most efficient manner (e.g. drilling water-producing pressure relief wells, back producing CO_2 from the site, reservoir intervention/remediation).

Planned MMV activities include (Global CCS Institute, 2013):

- Well-head pressure and temperature measurements during CO_2 injection;
- CO_2 injection rates measurements – both cumulative onto the offshore platform and individually per well;
- Bottom-hole pressure and temperature measured during CO_2 injection;
- Storage formation temperature measured during drilling operations;
- Formation fluid sampling for pH, chemical composition (including presence of tracer chemicals), salinity, density and microbial content acquired during drilling (and potential brine producers for Endurance);
- Saturation (CO_2/formation fluid) and resistivity measurements acquired during drilling and wire line logging;
- Well integrity measurements (e.g. annulus pressure, corrosion, cement bond logs, soil gas detection);
- Geomechanical indicators (e.g. micro-seismic);

- Baseline terrestrial vegetation, soil gas, water chemistry and pH surveys/measurements for comparison with similar measurements acquired post-injection;
- Baseline atmospheric surveys/measurements of CO_2 concentration for comparison with similar measurements acquired post-injection;
- Surface/seabed deformation measurements resulting from uplift (or subsidence) due to CO_2 injection operations.
- 4D seismic survey: this is a time lapse method which involves acquisition, processing, and interpretation of repeated seismic surveys over a long time duration covering the CO_2 store. The objective of the seismic surveying is to determine the changes occurring in the store as a result of CO_2 injection by comparing the repeated datasets. A typical final processing product is a time-lapse difference dataset (i.e., the seismic data from the earlier survey is subtracted from the data from the later survey). The difference should be close to zero, with the exception of where changes have occurred in the store. The 4D seismic survey is very costly as this requires an offshore survey vessel to cover the whole of the subsurface store.

6.7 Inspection and Condition Monitoring

Routine inspections would be carried out by the O&M Team (refer to Attachment 1) which includes Engineers and QC personnel.

Day to day condition monitoring would be undertaken by the operators with support from the Performance Engineering team and the Engineers within the O&M organisation.

Condition monitoring support of high value equipment such as turbines and centrifugal compressors would be sub-contracted to OEMs through support contracts. This would allow specialist engineering support from OEM service centres to be available to the O&M organisation should there be deviant indicators within the instrumented readings or performance.

Statutory inspection would be sub-contracted to competent persons (e.g. Annual Inspections under LOLER). This is included as a sub-contract (please refer to Attachment 4 to this document).

6.8 Insurance

Insurance for the plant is estimated as 2.4% of the CAPEX per Annum (Rider Hunt International, 2015).

Additional insurance will be required for the Carbon Store.

6.9 Local Rates, Taxes, and Utility Tariffs

Local Rates

Business rates are calculated based on the 'rateable value' of the property owned by the Power Generation Facility. Power Stations tend to own large areas of land which can have a high value which means that Power Generation Stations pay some of the highest business rates in the United Kingdom (The Guardian, 2015).

There is a loose correlation in the available data that indicates that the business rates bill for a CCGT + CCS plant in the England would be around £10m per annum for a 5 train plant and around £5m per annum for a 1 train plant. This assessment of the business rates is approximate and would require a detailed valuation to calculate an actual rate. Relief is available for business rates depending upon development areas. HM Treasury have also received impact from the Power Generation Industry that the current approach to the calculation of business rates penalises carbon reduction technologies which require more assets and property than an equivalent higher carbon emitter.

Taxes

The following taxes may be considered in the economic analysis of operating costs; however, these are not included within the OPEX model costs. Payroll taxes are included in the model:

- Corporation Tax. The current corporation tax rate is 20%;
- Value Added Tax (VAT);
- National Insurance. Taxes associated with personnel are included within cost of employment within the cost estimate (e.g. National Insurance Contributions, Apprentice Levy);
- Stamp Duty payable on transfer of assets (assumed = 0);
- Capital Gains (assumed = 0);
- Capital Allowances providing tax relief on Investment in plant and machinery, write downs of assets, environmental investments, and research and development.

Utility Tariffs

Major utilities, such as natural gas, are included under the Variable Costs as their consumption, and thus cost, are proportional to the operation of the plant.

Utilities in this section are those that are fixed regardless of the operation of the plant and include Telecomms connection, sewage, and small power for the manned facilities on the Onshore Plant.

Transmission Charges

National Grid Transmission Network Use of System charges (TNUoS) have been considered in the operating costs. These charges, levied by National Grid to cover the cost of installing and maintaining the electricity transmission system, have been published by National Grid and vary by region from £7.12/kW for North-eastern England, £2.76/kW for Yorkshire/Humber, £1.13/kW for North Midlands, and £24.61/kW in North Scotland. For the OPEX estimate, £7/kW was used (National Grid, 2017) .

Balancing Service Use of System (BSUoS) charges are a fixed daily fee applied to generators for the operation of the transmission system, and is estimated at £2.29/MWh for 2017/2018 (National Grid, 2017). These are included in the OPEX estimate within Transmission Charges.

6.10 Decommissioning and Handover to Abandonment Contractor

At the end of the plant life the asset will require to be decommissioned. The O&M costs will include provision for decommissioning activities:

- Decommissioning planning and risk assessment activities;
- Update of drawings to correctly specify the scope for decommissioning and abandonment;
- Shut down of power generation and process systems;
- Pump down of all wastes to treatment and disposal;

- Depressurisation of pressure systems, safe venting, and purging of flammable systems;
- Flushing of hazardous systems and treatment followed by disposal of flushing effluents;
- Shut down and de-energisation of systems;
- Return of hired plant, equipment, and packagers to owner;
- Sales or disposal of surplus consumables, stores, and spares;
- Plant should now be empty, flushed clean, and de-energised for onshore, subsurface, and offshore abandonment activities.

6.11 Fuel and Utilities

Fuel and Utilities consumption can be found in Attachment 3 – Utility Schedule – which is based on the work carried out for the Detailed Report: Plant Performance and Capital Cost Estimating, Doc Number: 181869-0001-T-EM-REP-AAA-00-00004 (ETI ref: D4.1).

Fuel pricing has been analysed based on data published by OFGEM detailing the wholesale market indicators the UK gas and electricity markets (OFGEM, 2017). The 5-year average price of 50 p/Therm has been selected for the cost model as a reflection of the current market conditions.

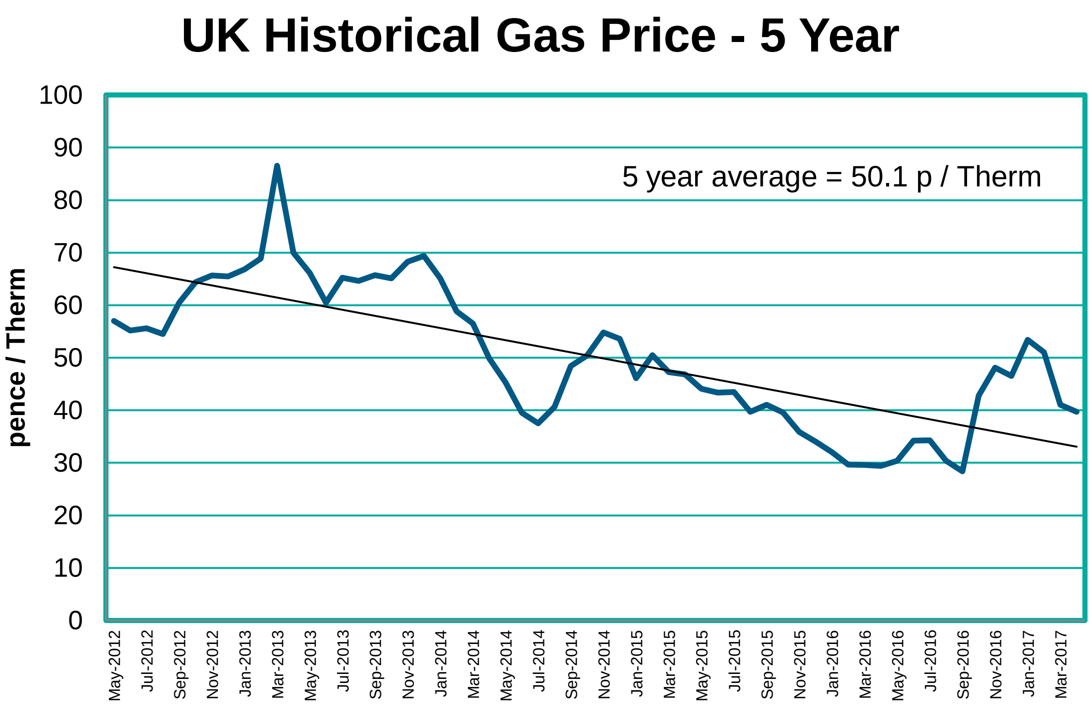


Figure 4 – UK Historical Gas Prices

6.12 Chemicals and Catalysts

Chemicals consumption can be found in Attachment 3 – Utility Schedule – which is based on the work carried out for the Detailed Report: Cost Estimating, Doc Number: 181869-0001-T-EM-REP-AAA-00-00004 (ETI ref: D4.1).

No significant catalyst consumption is expected within the Process Plant.

6.13 Waste Disposal

The following wastes are considered for the cost estimate:

- Waste water is treated and then returned to near the water abstraction location. There is a license cost associated with water abstraction and discharge.
- Degraded Amines – intermittent disposal from drain tank to offsite licensed waste disposal contractor. Assume 33m^3 per train per week. An allowance is also required for spills from Amine containment following maintenance intervention – assume 95m^3 of engineered Amine Solvent per annum;
- Dehydration molecular sieves – disposed of in landfill every 3 years – (£82.60/t for active waste and £2.60/t inactive waste). Molecular Sieve is not ignitable, corrosive, reactive, toxic, or environmentally damaging and therefore can be treated as inert;
- Waste Water / Effluent Treatment Plant sludge - disposed of as an active waste;
- Compressed air package desiccant - disposed of in landfill every 3 years as an inert waste;
- Lubricating oils - intermittent disposal by offsite licensed waste disposal contractor. Assume that entire oil inventory is replaced at every major shutdown for cost estimation;
- Other intermittent waste streams will require sorting on site for recycling purposes (e.g. different skips) and disposal by offsite licensed waste disposal contractor.
- All costs related to abandonment are 2016 values. No escalation or discounting has been applied.

6.14 Emissions

Emissions legislation has two components:

- Carbon Price Support – 2016 cost – set at £18 / tCO_2 (HM Revenue and Customs, 2014). The Carbon Price Support is levied on owners of power generating stations based on the carbon content of fuels. Exemptions or reductions on the Climate Change Levy which may be possible through consultation with the Environment Agency have not been considered.
- Carbon Credits - 2016 - £4.18 / tCO_2 (BEIS, 2017) – Carbon credits are a government issued instrument which allow a producer to emit one tonne of CO_2 and are readily traded by generators and investors. For the purposes of this estimate, carbon credits are considered a financial instrument and not a part of OPEX.

6.15 Exclusions

This estimate does not make allowances for:

- Financing costs
- Transmission grid upgrades
- Carbon Credit (considered as revenue)

7 Estimate Methodology

The overall cost estimate methodology involves building up the cost estimate from the plant operating conditions. The plant operating conditions were modelled in GTPro and Aspen HYSYS, the carbon capture unit was scaled from Shell Peterhead CCS, and the results were used to develop utility schedules, maintenance schedules, and consumable / disposal volumes. A staffing plan was generated based on prior project experience and stakeholder input.

Costs were applied to these schedules from vendor quotations from prior projects wherever available. In some cases, vendor quotations were scaled up to match the scope of the modelled plant. Additional cost data was derived from publicly available sources, such as published trade rate data and historical gas pricing.

An operating cost model was built fitting the costs into fixed and variable categories, and spreading over an operating timeline. Fixed costs vary with the number of trains. Variable costs are affected by the operating availability of the plant and number of trains.

Once the operating cost model was produced, the costs were peer reviewed by subject matter experts within SNC-Lavalin and compared to a set of benchmarks for similar power generation and CCS projects.

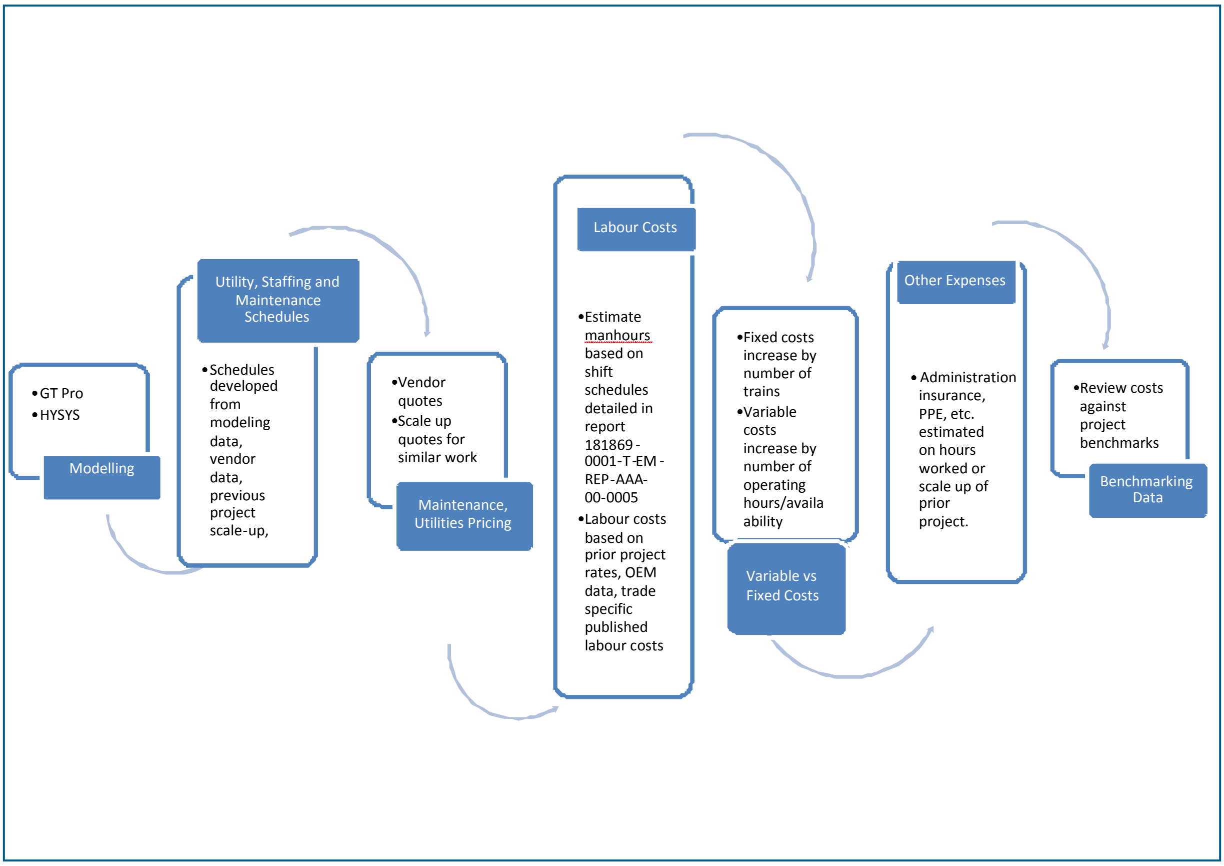


Figure 5 – Estimate Process

8 Estimate Assumptions

The Generic Business Case estimate has been built upon a set of key assumptions. This section will lay out those assumptions from an overall scheme perspective.

Overall Assumptions

- Labour, equipment, and materials cost and availability is based on current market conditions. No uplift or savings have been considered based on future anticipated market activity (including commodity pricing)
- Costs are based on 2016 pricing
- No forward projections on fuel, commodity, staffing, or other expenses have been added
- Local staffing or permanent relocations are assumed to be available for the duration of the Operation of the CCGT + CCS scheme.
- The plant operating life is 25 years per the Detailed Report: Plant Performance and Capital Cost Estimating , document 181869-0001-T-EM-REP-AAA-00-00004, ETI ref D4.1).

- The fuel cost has been assumed at a 5-year average rate as of April 2017 at 50.1 p/Therm. The operating cost model assumes a constant cost of gas.
- Quantities of consumables have been based on the Utilities Schedule, included as Attachment 3. Quantities used are based on plant availability and on a per train basis.
- A spare parts inventory has been assumed for the CCS portion of the plant based on work done on Shell Peterhead CCS. This was compared to the total cost of equipment for the area, and the ratio was used to apply a spare parts allowance to the other areas of the plant.
- Wholesale water and abstraction costs are based on volumes from plant modelling and rates garnered form the latest available government publications (Northumbrian Water Ltd., 2016) (Environment Agency, 2016).
- Subcontract requirements and costs based on prior project experience
- Administrative expenses scaled up based on prior project experience
- Availability is calculated based on planned and forced outages (see section 5.2). An additional reduction in availability was assumed for years 1 and 2 attributable to performance management and learning curves. These figures were based on consultation with prior project personnel and industry experts.
- Cost of Carbon is set at £18/Tonne based on 2015 rates as per the 2016 Autumn Statement, stating the rates will be capped until 2020 (HM Revenue and Customs, 2014)
- Costs have been allocated between CCGT, CCC, Transportation, and Offshore. Where costs are not directly attributable to an area, such as Executive Management or Administrative expenses, they have been allocated as a proportion of staffing cost per area.

9 OPEX Estimate

The OPEX estimate for the Thermal Power with CCS project covers the phase from the end of the start-up period, or commercial operation date, to decommissioning and post-injection well monitoring, presented in two sections, Operating Expenditure (OPEX) and Decommissioning and Abandonment Expenditure (ABEX).

A robust estimate has been created from the bottom up, using detailed modelling work and industry expertise as the basis for the maintenance, utility and consumables, and staffing schedules used as the foundation of the cost model.

Fixed costs are scalable based on the number of trains being constructed, whilst the variable costs are modelled to reflect the anticipated availability of the plant. An example of the split of OPEX is shown in Figure 6. Year 4 has been chosen as it is nearest to an overall average OPEX cost for the lifetime of the plant. No major maintenance or shutdowns are planned for Year 4 of operation.

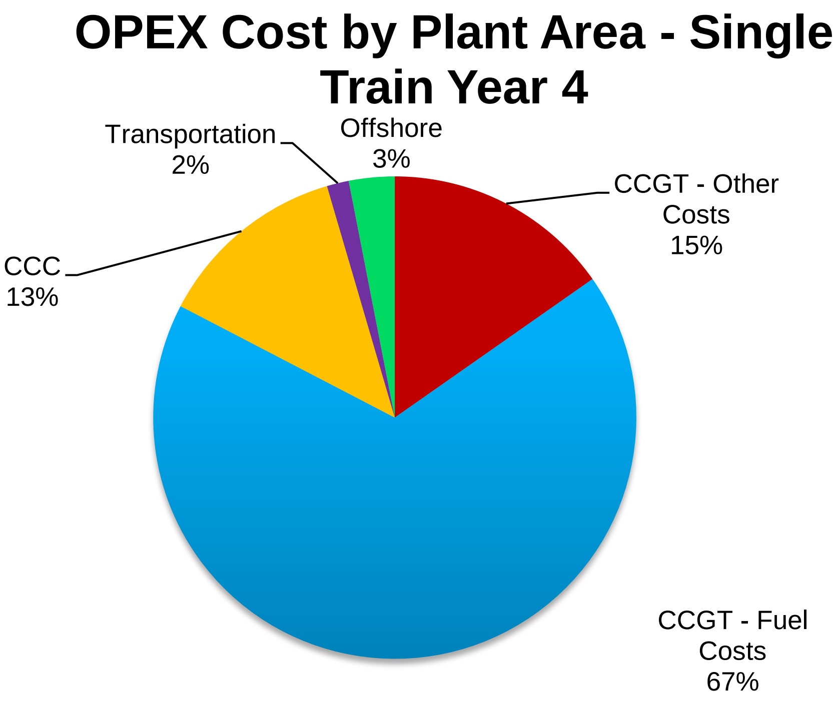


Figure 6 – Annual OPEX by Plant Area – Year 4

9.1 Estimated Annual OPEX Cost

The following table is the annual OPEX cost for one train, year 4 of operation, with 98% availability.

Area	Cost – Single Train (m)	Included
	£188.3	**Variable**
	0.27	Utilities
	172	Fuel Gas
	7.9	Consumables
	0.19	Disposals
CO_2	4.34	Carbon Cost
	3.17	Cost for Restarts
	£70.9	**Fixed**
	6.2	Maintenance
	10.4	Staffing
	0.03	Regulatory
	2.7	Fixed Subcontracts
	51.6	Administrative and Other
	£259.1	**Total**

Table 10 – OPEX Cost Summary

9.2 Fixed Costs per Annum

Fixed costs do not fluctuate based on the operation of the units. They are scaled based on the number of trains built, but do not change due to planned or forced outages, or changing operating conditions of the plant. Fixed costs include direct operations and maintenance labour, scheduled maintenance, regulatory expenses, some subcontracts, and administrative and overhead expenses.

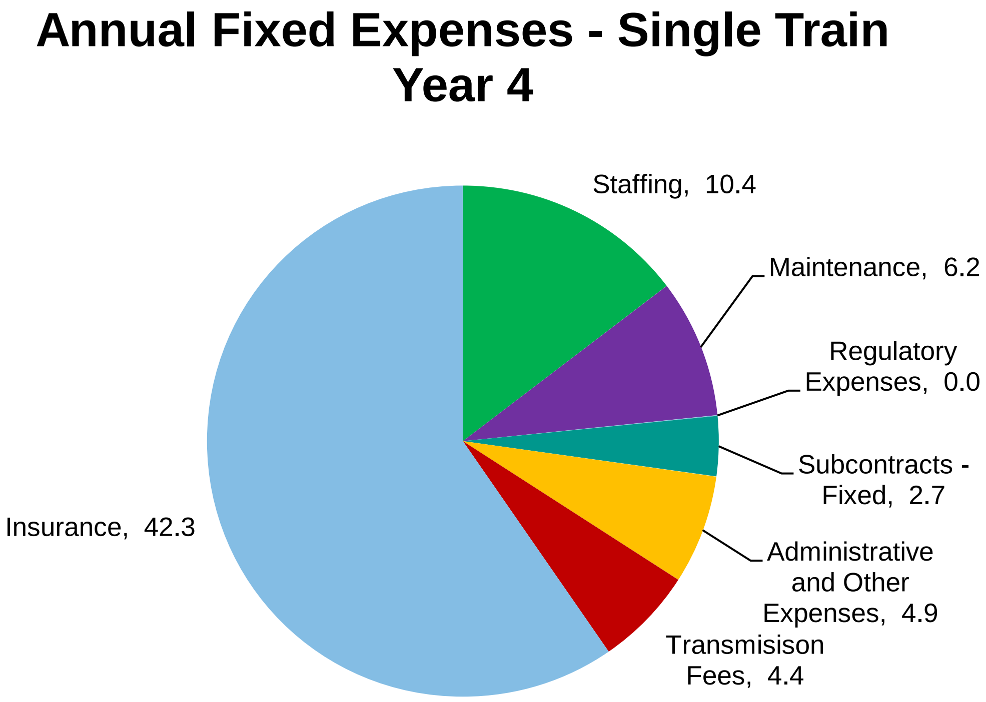


Figure 7 - Fixed Expenses

Administration/Other Expenses

The fixed expenses are dominated by insurance costs (61%), whilst approximately 6% relate to transmission fees; these are included in the administrative and other expenses section of the OPEX estimate, but have been split out separately in Figure 7. It should be noted that there is a wide range of insurance rates quoted in the available literature and this study selected a conservative approach. The insurance costs have been estimated based on information available through Teesside Collective and equate to approximately 2.4% of CAPEX (Rider Hunt International, 2015). An allowance has been made for financial security of the CO_2 stores, which has been prorated based on MTPA output and equates to 2% of the total administrative costs and included in the Storage area of the OPEX estimate. The remaining administrative expenses relate to general office and personnel administration, PPE, local taxes, and financial and auditing requirements.

Maintenance & MMV Costs

Maintenance costs are the second most dominant area of fixed expenses. Whilst they are considered fixed, they vary year to year depending on the planned maintenance required for the plant. For example, the largest planned maintenance expenditure for the CCGT area of the plant occurs every 12 years, when a full inspection and overhaul is required for both the gas and steam turbines. Please refer to Attachment 2 of this report for the maintenance cycle.

The maintenance cost section includes materials and specialised subcontracts for non-routine maintenance. Routine maintenance costs are included in the staffing area of the estimate. Major subcontracts for shutdown maintenance outside of the major pieces of equipment i.e.) turbines, are included in the subcontracts section of the estimate.

The main item of significance in the maintenance schedule of the carbon capture and compression area of the plant is the overhaul of the CO_2 compressor which is estimated to occur every 6 years, at a cost of approximately £250,000 per unit. The remaining maintenance of the CCC area is performed by the in-house operations and maintenance team using the 2-years spares inventory.

Pipeline maintenance costs include route surveys, cathodic protection surveys, internal inspections, equipment testing and inspection, and leak testing. The overall maintenance budget for pipelines has been estimated based on data from the Teesside Collective and set at 0.5% of the capital cost (Rider Hunt International, 2015).

Offshore maintenance costs are dominated by a 4D seismic survey required every 5 years to detect any migration outside the storage site. This survey is accompanied by additional monitoring and sampling to look for any indicators of loss of containment. After Year 15 (not included in costs in Figure 8), a heavy workover of the wells may be required at a cost of £15 million. Other offshore maintenance included in this figure is a 10 yearly wireline logging suite. The remainder of the offshore maintenance expenses, such as well washing, are included in the operations and maintenance staffing costs, with the W2W vessels covered under the subcontracts area.

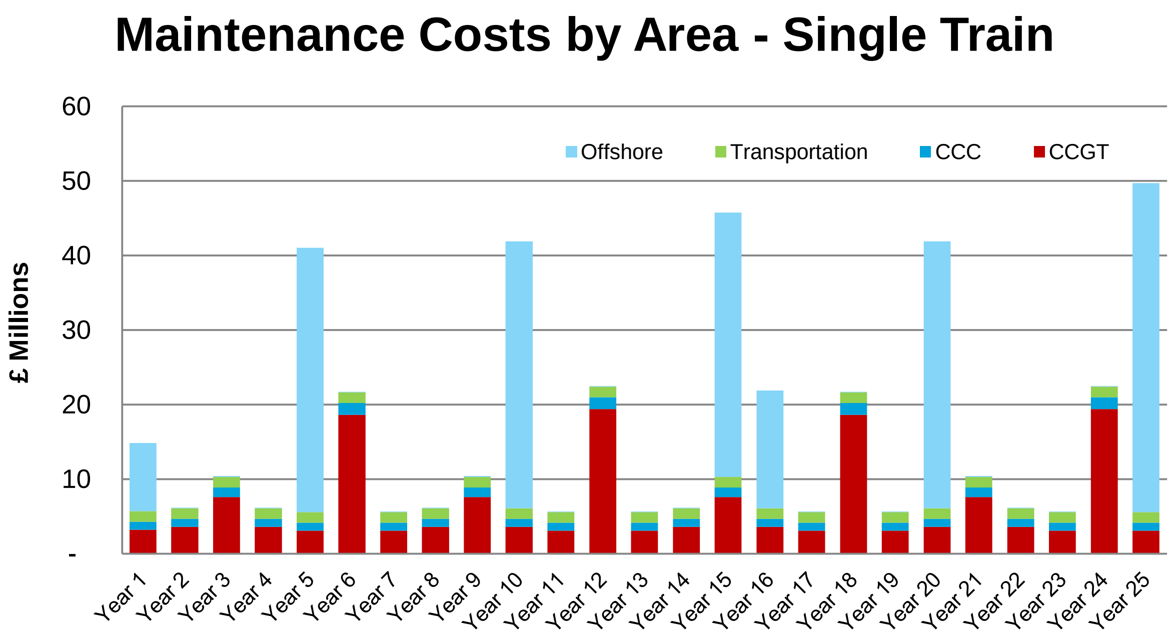


Figure 8 - Maintenance Costs by Area

Staffing

Staffing expenses have been built up using direct labour requirements for the CCGT-CCS trains and augmenting with the required administrative and management positions. See Attachment 1 for a detailed organisational chart.

The shift pattern assumed is for 24 hours operation by 6 teams, with one team rotating out to do offshore inspection and maintenance. Labour levels have been optimised for each number of trains, rather than directly scaled. Staffing requirements were first estimated based on a 5 train plant, then analysed to ensure that with each reduction in train, the staffing levels were as low as reasonably practicable to allow a safe and effective operation of the plant. Positions such as the Injection Chemist and Workover Engineer, and other offshore specialists have been considered as part-time positions. Details of the scaling of staffing levels by plant size can be found in the OPEX model in Attachment 8. Labour costs have been attained from SNC-Lavalin data, industry publications, and publicly available sources. Overtime and shift premiums have been added for those positions on the rotation schedule, and an administrative allowance for employment costs and benefits has been included.

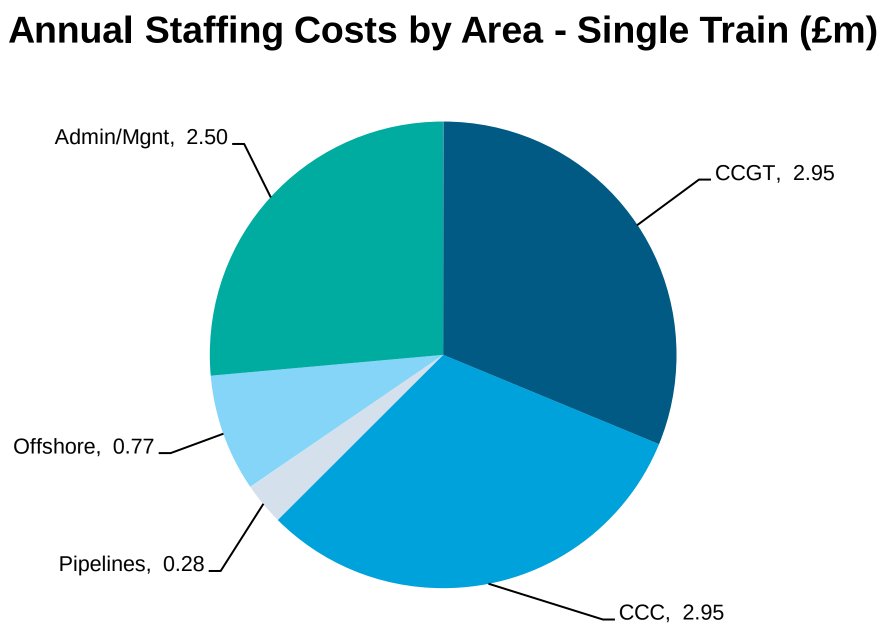


Figure 9 - Labour Costs by Area

Fixed Subcontracts

Subcontracts have been estimated for general security and cleaning, and logistics, which have been allocated between CCGT and CCS areas. Additional fixed subcontracts are included for subsea pipeline inspection every 5 years, offshore survival training, and walk to work and supply vessels. These represent less than 0.7% of the overall OPEX cost.

Additional fixed subcontracts relate to O&M specialist contractors for shutdowns, turnarounds and non-routing maintenance, scaffolding and non-destructive testing support. Shutdown support is estimated for 57 days every 6 years for a full plant shutdown, based on the maintenance schedule for the gas and steam turbine overhaul. Costs have come from SNC-Lavalin prior project and proposal data, and for the intervals between major shutdowns, are approximately £1.1 million per train. Major shutdown contractors are estimated at £11.3 million every 6 years.

Please refer to Attachment 4 for major sub-contracts.

Regulatory Expenses

3rd party inspection and test costs will be required in order to maintain regulatory compliance: for example, in accordance with the provisions of the Lifting Operations Lifting Equipment Regulations (LOLER), Provision and Use of Work Equipment Regulations (PUWER), Pressure Systems Safety Regulations (PSSR). 3rd party inspections may also be required by the insurer. The cost estimate is based on a previous project.

9.3 Variable Costs

Variable costs within the OPEX estimate are a function of plant availability, discussed further in Section 5.3. The CCGT section of the GBC scheme dominates the overall variable costs due to the cost of fuel gas.

The plant availability is based on best available data for CCGT plants from OEMs and the Project Team's experience designing over 49,000 MW of thermal power plants combined with SNC-Lavalin experience with carbon capture and storage. As the carbon capture is expected to have a slightly lower reliability factor of the two major plant areas, it drives the forced outage frequency in the estimate. The availability calculations are discussed in detail in Section 5.2.

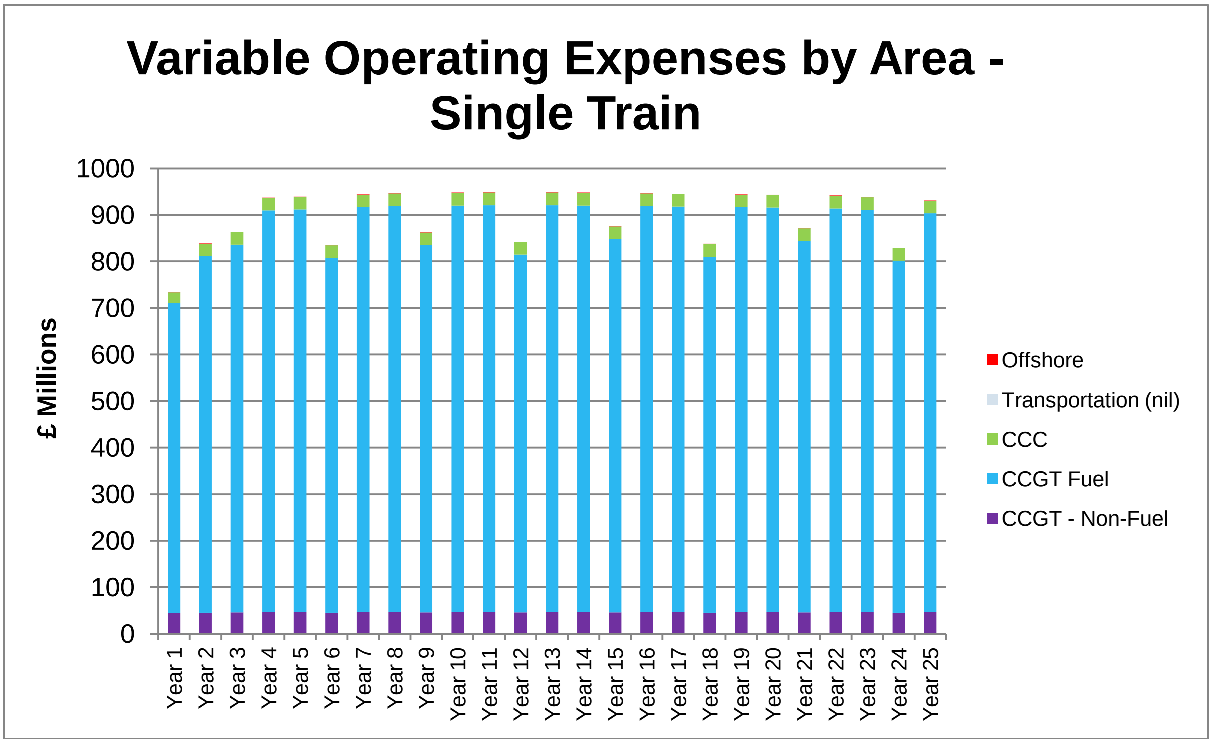


Figure 10 - Variable Operating Expenses by Area

Fuel Gas

The most significant cost for the operation of the plant is the cost of fuel. The OPEX model has been estimated on a fuel cost of 50.1 pence per Therm. This is representative of the 5-year average in the UK wholesale natural gas market (OFGEM, 2017). As the cost of fuel accounts for more than 65% of the total operating cost, the commercial operation of the plant is highly sensitive to a change in the natural gas price.

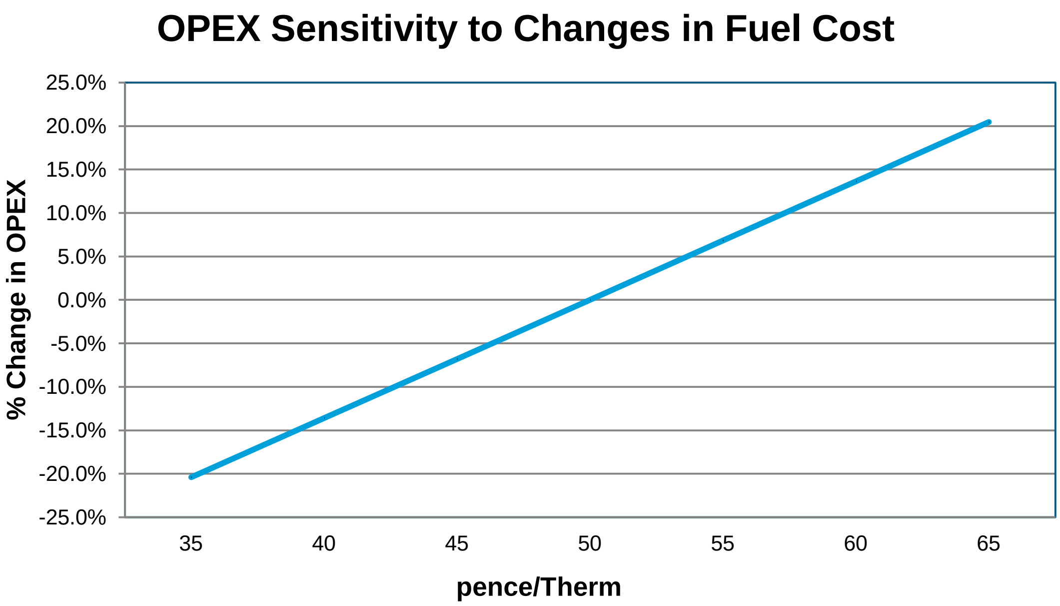


Figure 11 - OPEX Sensitivity to Change in fuel Cost

Utilities

Utility costs include water use, both towns water and raw water, as well as hydrogen, nitrogen and CO_2 used for fire suppression. Usage rates can be found in the utilities schedule, detailed in Attachment 3. The costs have been obtained from publications on municipal water and water abstraction charges (Northumbrian Water Ltd., 2016) (Environment Agency, 2016). Chemical pricing has come from SNC-Lavalin database sources. At approximately £276,000 per train, the cost of utilities is representative of only 0.1% of the overall operating cost of the plant.

Consumables

Consumables included in the OPEX estimate include the chemicals and catalysts used in the general operations of the plant. Two main items are material to the overall cost: Engineered Amine and Sodium Hydroxide (NaOH), making up over 60% of the cost of consumables. The costs for consumables have been obtained from prior project and proposal data and publicly available sources, as listed below.

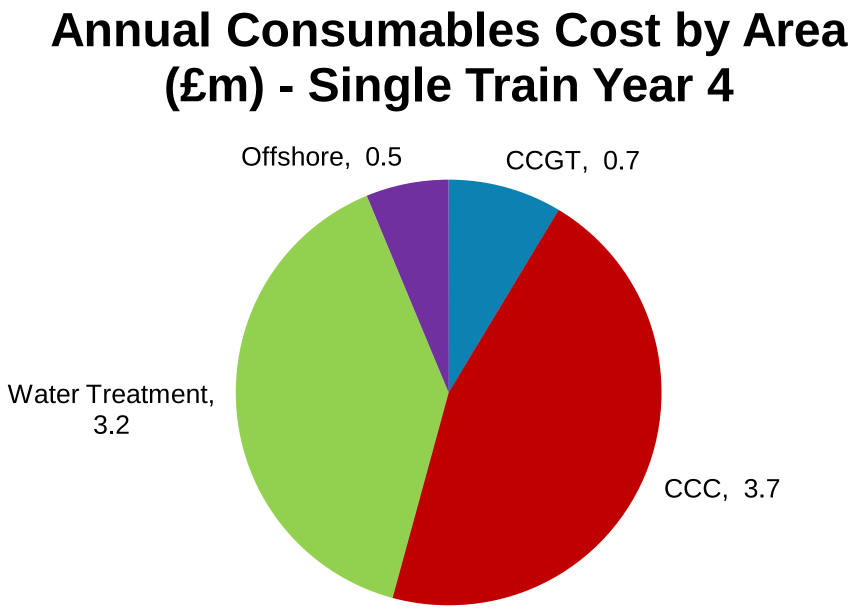


Figure 12 - Consumables Cost by Area

Sodium Hydroxide is used in water treatment, amine treatment, and demineralisation package. Usage rates can be found in the Utilities Schedule (Attachment 3) and usage is scaled based on plant availability.

Amine solvent is used to separate the CO_2 from other exhaust gases produced by the combustion of natural gas in the CCGT unit. This is detailed in Section 4.0 – O&M Philosophy. Amine usage has been estimated based on publicly available data from the Global CCS Institute relating to the comparison between engineered and standard amine solvents used in CCS process facilities (Global CCS Institute , 2012). As per the Global CCS Institute, the cost of MHI's engineered amine solvent (KS-1) is 5 five times more expensive than conventional MEA. The solvent degradation, however, is only 10% of conventional MEA degradation. These figures will depend on the engineered amine selected for absorbing CO_2; however, the figures provide a baseline to use as a cost for the estimating data. The first fill quantities of amine were accounted for in the capital cost estimate.

Additional cost allowances have been made for diesel fuel for generator sets, lube oil for the turbines, and additional chemicals required for water treatment. For the Overall OPEX by area the water treatment is split between CCGT and CCC.

Carbon Cost

The cost of carbon has been estimated at £18 per tonne as per UK government publications (HM Revenue and Customs, 2014). The carbon price is expected to remain capped until after 2020 (HM Treasury and Rt Hon Philip Hammond MP, 2016). For the purposes of this estimate, the current rates are assumed constant for the duration of the operating life.

Please refer to section 5.6 of this report for the Carbon Capture rates.

Based on an estimated availability of 95% in Year 4 and 3 cold, 4 warm, and 5 hot starts, the cost of the Climate Change Levy would be approximately £4.3 million. Of this, £3.7 million relates to the plant running at full capacity, £0.6 million due to emissions during unabated operation (start-up, etc), and £0.03 million for the auxiliary boiler running whilst the plant is shut down. This accounts for a capture rate of 90% whilst the plant is running at full capacity, as well as additional costs for restarting the plant whilst it is running unabated. For a cold start, it is estimated that a period of 20 hours unabated is required. This is detailed further in Section 9.4 – Indicative Costs per Start. For simplicity, the carbon costs are based on a plant that is either running at capacity or not running. There are no factors added for a turndown at this time.

Carbon credits, which are instruments issued by the government for low carbon technologies and traded by investors and generators, are not considered in this estimate. They are discussed further in Section 6.14.

9.4 Indicative Costs per Start (Cold, Warm, and Hot)

Equivalent hot starts (EHS) calculations are typically used to evaluate the impact of different operating modes of a plant on plant performance and O&M costs. In this instance, EHS methodology is used to apply the widely used 1:3:5 ratio to hot, warm and cold starts (Shibli, Akther, & Hampson, 2015).

A cost estimate has been prepared to account for the plant fatigue and additional fuel burn associated with a cold restart.

Restart Cost Element	Rate	Cost Impact (£)	Note
Cold Start = 50 EOH for Gas Turbine (allow 2 days)	3,442	6,883	Cost impact of shortening CCGT life until major overhaul
Fuel Burn Before Synchronised	0.18	3,836	40 minutes @ 113,400 / NM^3/hr x £0.xx (rate in Utilities Schedule)
Fuel Burn before CCS	0.18	415,091	20 hours @ 113, 400 NM^3/hr x £0.xx (rate in Utilities Schedule)
Total cost impact		**495,810**	**Does not include lost revenue as that is in availability calc.**

Table 11 - Cost of a Cold Restart

Costs for warm and hot restarts have been calculated using the 1:3:5 ratio.

Projected Starts per year	EHS	Cost Impact (£)
Hot Starts	1 EHS	99,162
Warm Starts	3 EHS	297,486
Cold Starts	5 EHS	495,810

Table 12 - Cost of Cold, Warm and Hot Starts

The number of starts have been based on SNC-Lavalin experience with CCGT plant design, DECC published figures (DECC), as well as SNC-Lavalin experience with CCS design and start-up. Restart costs in the operating model account for 3 cold, 4 warm, and 5 hot starts per annum.

9.5 Summary of 5-4-3-2-1 Cost Model

Most costs increase on a linear basis with the increasing number of trains. The main area where economies of scale exist is with staffing costs. Because staffing levels have been optimised for each number of trains and opportunities exist for teams to work on multiple units, savings are possible as the number of trains increase.

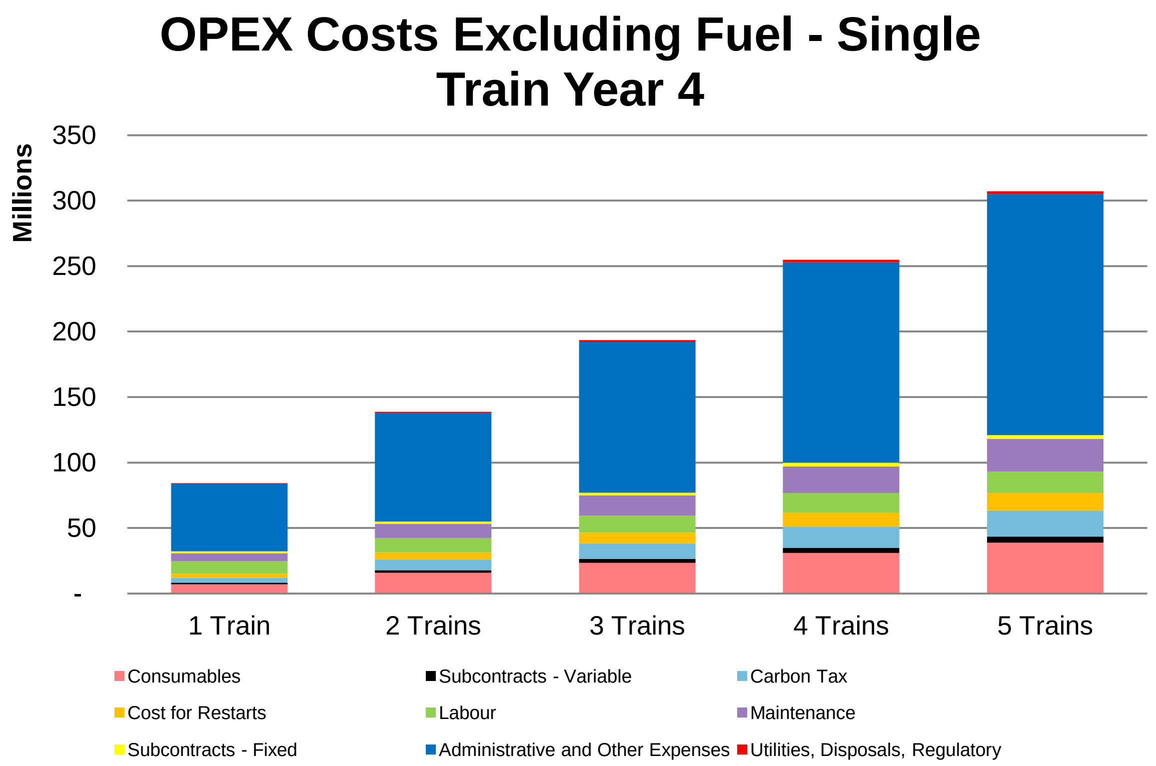


Figure 13 – Annual OPEX Costs for 5-4-3-2-1 Trains

Annual output for each location based on the maximum number of Trains per site and expected availability is as follows:

Location	Net Abated per Train (MW)	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
Teesside - 5 Train	621.43	24.04	25.68	23.66	25.81	25.88	22.82
North Humber - 5 Train	621.43	24.04	25.68	23.66	25.81	25.88	22.82
South Humber - 5 Train	621.43	24.04	25.68	23.66	25.81	25.88	22.82
North West - Gas - 3 Train	622.84	24.10	25.73	23.71	25.87	25.94	22.87
North West - Liquid - 3 Train	621.00	14.42	15.39	14.18	15.48	15.52	13.68
Scotland - 3 Train	614.00	14.25	15.22	14.02	15.30	15.34	13.53

Table 13 – TWhr Output per Annum by Location

Differences in output by location are due to varying parasitic load, with additional shoreline compression required for the Scotland location and chillers necessary for the North West liquid option: please refer to the Detailed Report: Plant Performance and Capital Cost Estimating, document reference 181869-0001-T-EM-REP-AAA-00-00004 (ETI Ref: D4.1).

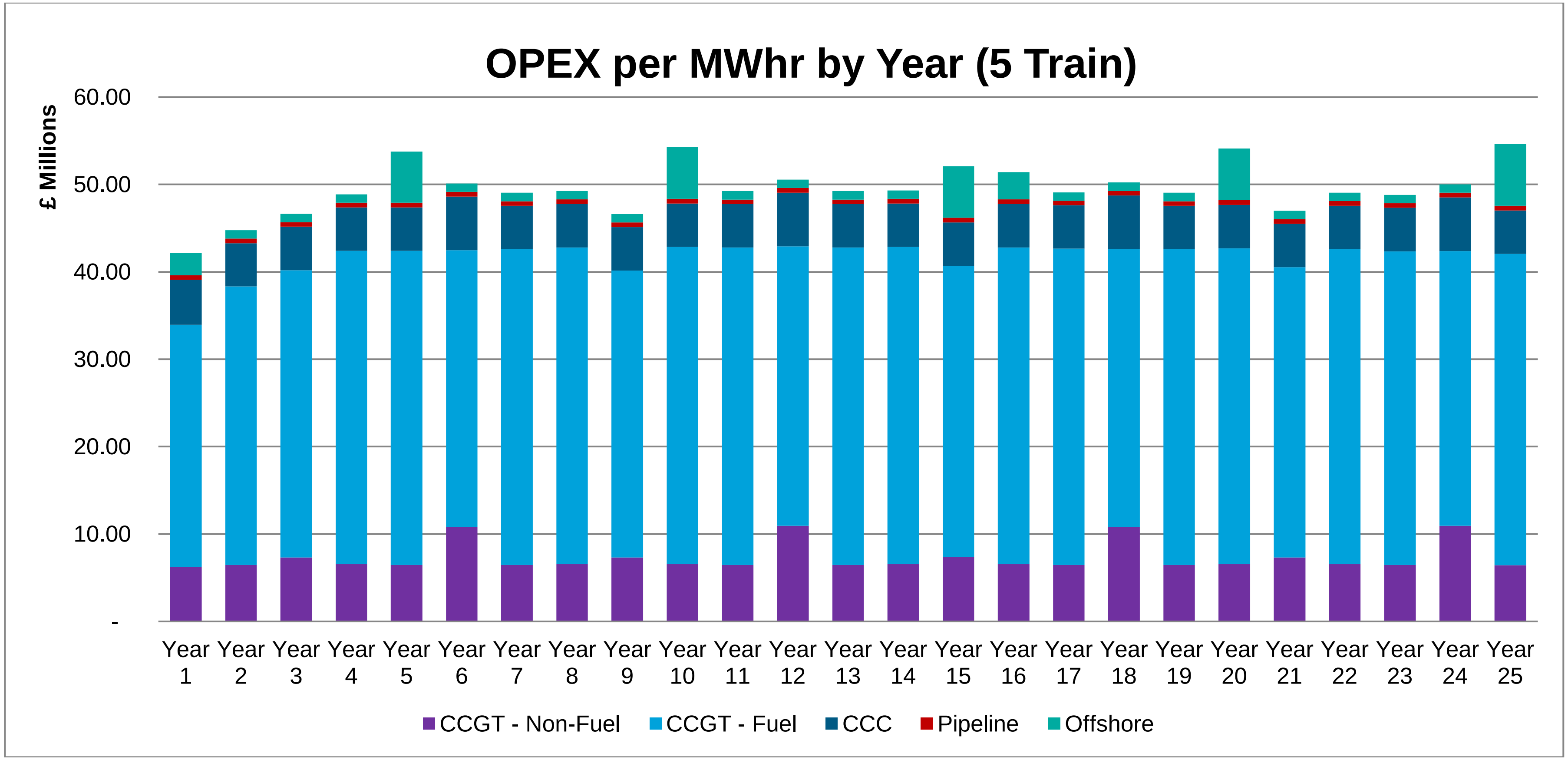


Figure 14 - OPEX per MWhr by Year

Figure 14 represents the OPEX cost per MWhr which factors plant availability into the OPEX cost model. Peaks in years 5, 10, 15, and 20 occur due to costs for periodic seismic inspections occurring in these years. Overall, the cost per MWhr is lowest in years with high expected availability and no significant maintenance events.

9.6 Summary of Regional Differences

Separate models have not been generated to detail the regional differences between the selected sites. Some small variations may exist in staffing cost, wholesale towns water cost, or wayleave cost; however, these are not of significance to the overall cost model. For example, a decrease of 5% in labour costs would represent only a 0.19% impact on overall OPEX (single train).

Costs for the North East regions increase for 4 and 5 trains due to the addition of the second offshore platform, as do costs for Scotland beyond 1 train. Additional consumable costs of £510,000 per year as well as additional maintenance for well washing and additional monitoring costs would be included.

Transmission costs vary between regions as well, from £7.12/kW for North-eastern England, £2.76/kW for Yorkshire/Humber, £1.13/kW for North Midlands, and £24.61/kW in North Scotland. For the OPEX estimate, £7/kW was used (National Grid, 2017) .

10 Decommissioning and Abandonment Expenditure (ABEX)

Preparation for abandonment and handover to decommissioning subcontractor has been estimated based on a 12 month planning period and a one month schedule for shutting down and making safe. A portion of the costs are considered within the final year of the OPEX budget i.e.) staff time required for planning, assessing risk, updating drawings and specifying the scope of decommissioning and abandonment, and the shutdown of power and process systems.

An additional cost for pumping out of systems, depressurising, venting, and purging, flushing, making safe, and disposal or resale of remaining consumables are planned for 1 month post shutdown and require 75% of the O&M staffing levels.

Additional allowances have been made for site surveys for ground contamination to ensure accurate scoping of abandonment subcontract.

Handover to Abandonment Contractor	5 Trains	4 Trains	3 Trains	2 Trains	1 Train
12 months leading up to shutdown	n/a, included in Year 25 of the OPEX estimate				
O&M Staff (75% level) 1 month to depressurise and make safe	1,039,481	962,093	838,483	718,318	628,896
Ground contamination surveys	330,000	275,000	220,000	165,000	110,000
Total Handover Cost	**1,369,481**	**1,237,093**	**1,058,483**	**883,318**	**738,896**

Table 14 - Handover to Abandonment Contactor

Decommissioning and Abandonment costs have been considered for each area of the plant. No variance has been considered between onshore sites, though separate estimates have been prepared for the offshore installations and pipelines. Note that the CO_2 transport costs for Scotland include the abandonment of the 198km Feeder 10 pipeline.

No. Trains	5 Trains	5 Trains	5 Trains	3 Trains	3 Trains
Area	**Teesside**	**North Humber**	**South Humber**	**Northwest**	**Scotland**
CCGT	73.1	73.1	73.1	43.9	43.9
CCC	39.5	39.5	39.5	23.7	23.7
CO_2 Transport	10.3	6.9	6.5	5.3	20.9
Offshore Platform	147.8	147.8	147.8	59.1	162.6
Total Cost (£m)	**£270.7**	**£267.3**	**£266.9**	**£132.0**	**£251.0**

Table 15 – Decommissioning and Abandonment Costs

CCGT costs have been evaluated based on projects completed by Brown and Mason and published in their project portfolio (Brown and Mason, 2017). An average cost per MW was derived and applied to the nominal capacity of the Plant. It is assumed major systems will be drained and made safe, equipment will be dismantled and recycled wherever possible, buildings demolished, and site remediated to a usable state.

Carbon Capture decommissioning costs are based on decommissioning costs for process facilities, including a power station and refinery (Brown and Mason, 2017). A cost was calculated based on overall area and applied to the Plant area for CCS. It is assumed that the systems will be depressurised, drained, and made safe, the equipment dismantled and recycled wherever possible, and the towers and buildings demolished and rubble disposed.

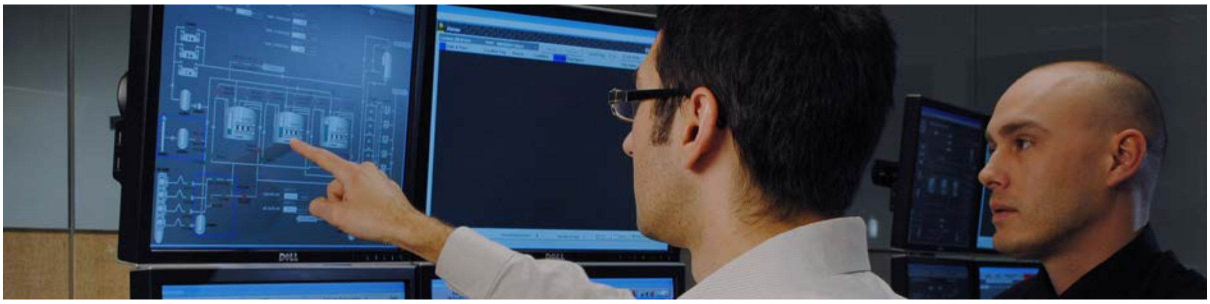
Pipeline decommissioning underwent an evaluation by Oil & Gas UK in 2013 and a report was published detailing regional variations and approximate costs per kilometre for offshore pipeline decommissioning (Borwell, 2014). It is assumed the pipeline will be depressurised and made safe, cut and lifted, mattresses removed, and metal recycled wherever possible. As offshore technology improves for lifting, trenching and cutting, it is possible these costs will decrease.

Onshore pipeline decommissioning has been evaluated based on applications to the Government of Canada including pipeline abandonment cost estimates by companies such as TransCanada Pipeline, Enbridge, Kinder Morgan, and Alliance Pipeline Ltd (National Energy Board, 2013). A range of $110 to $300 thousand per kilometre could be seen in the data; however, the lower end has been chosen as a basis due to gentler terrain, less remote conditions, CO_2 rather than hydrocarbon pipelines, and above ground installation.

The offshore costs are based on cutting and floating off the topsides, whilst the jacket is cut down/laid flat and abandoned in situ. Costs have been garnered from White Rose KKD and extrapolated using metrics from Decom North Sea research on offshore decommissioning projects in the North Sea (ARUP, 2014) (DECC, 2016).

Offshore Site	Endurance	Hamilton	Goldeneye	Captain X
Number of Wells	5	4	4	7
Weight of Topsides	2679	2530	1000	2781
Weight of Jacket	3160	1767	3000	4224
Weight of Piles	920	360	2500	1993
Water Depth (m)	59.3	24	121	115
Cost (£m)				
Running, Making Safe, and Preparation	13.30	10.64	10.64	18.63
Well Abandonment (Wet)	34.00	27.20	27.20	47.60
Well Abandonment (Dry)				
Facilities Removal	16.26	13.01	13.01	22.77
Topsides Prep and Removal				
Substructure Removal / Rig to Reef Programme				
Subsea infrastructure removal/make safe				
Site remediation	3.70	2.96	2.96	5.17
Topside and substructure recycling	0.74	0.59	0.59	1.03
Monitoring	5.91	4.73	4.73	8.28
Total Decommissioning and Abandonment Costs (£M)	73.91	59.13	59.13	103.48

Table 16 - Decommissioning of Offshore Topside and Jacket



11 Benchmarking

11.1 Staffing

The following data shows the level of staffing for projects relevant to areas of the CCGT + CCS scheme.

Source	Plant Type	O&M Team
Central Power Plant (CPP) University Central and Medical Campuses.	CHP 2 Trains	42
AmecFW report commissioned by the ETI	CCGT 2 Trains	50
West Burton CCGT (EDF Energy)	CCGT 3 Trains	50
White Rose (Capture Power Limited, 2016)	Oxy Fuel + CCC 1 Train	96
Spalding (Johnson Press, 2013)	CCGT and OCGT 2 Trains	60
Peterhead	CCS 1 Train	Management = 11 Day Shift = 13 Night Shift = 7
Peterhead (Shell UK Limited, 2016)	Offshore Storage	12

Table 17 – Operation and Maintenance Team Size Benchmark

Combining the CCGT for 2 trains (50 people) with the Peterhead onshore manning (31 people) and the Peterhead offshore manning (12 people) provides a team for 2 trains of 93 people. This is a similar number to that required for the White Rose CCS project of 96 people. The equivalent manning level estimated for the GBC project (2 trains) is 127 people, but this does include Executives, Senior Management, Administration, and Reservoir Management which would not be represented in the

Benchmark figures: removing these people for a two train results in a manning level of 102 people which is close to the Benchmark.

The following Staffing costs were advised by Global CCS Institute (Global CCS Institute, 2012) for a two train CCGT + CCS. These costs exclude transportation and storage. These costs are for a 2010 cost base. The Benchmark has been increased for inflation to 2016 and compared to the cost from the OPEX model for a two train plant without Executives and Reservoir Management which would not be represented in the Benchmark figures.

<table>
<tr><th>Fixed Costs</th><th>Benchmark €M/annum</th><th>Benchmark £M/annum escalated to 2016</th><th>GBC Estimate £M/annum</th><th>Comments</th></tr>
<tr><td>Operating Labour</td><td>3.72</td><td>3.8</td><td rowspan="2">7.3</td><td rowspan="2">The GBC staffing costs are higher than that for the Benchmark.

The significant difference is that the benchmark figure is based on 62 people against 102 people for the GBC.</td></tr>
<tr><td>Labour Overhead</td><td>1.12</td><td>1.2</td></tr>
</table>

Table 18 – Benchmark of Staffing Costs

The major difference between the number of staff in the benchmark and the GBC is because there is additional staffing within the shift pattern in the GBC to cover transport and offshore operation and maintenance as the O&M team will cover the whole CCS chain.

11.2 Maintenance

The following Maintenance costs were advised by Global CCS Institute (Global CCS Institute, 2012) for a two train CCGT + CCS. These costs exclude transportation and storage. These costs are for a 2010 cost base. The Benchmark has been increased for inflation to 2016, scaled up from the benchmark size plant to the GBC size plant, and compared to the cost from the OPEX model for a two train plant.

Fixed Costs	Benchmark €M/annum	Benchmark £M/annum	GBC Estimate £M/annum	Comments
Maintenance	17.6	24.7	22.0	Maintenance costs vary year to year. Therefore an averaged CCGT + CCS over 25 years has been for comparison with the benchmark. The maintenance comparison from the GBC uses both direct maintenance costs and subcontract costs as these are both equivalent to the maintenance used in the benchmark

Table 19 – Benchmark of Maintenance

The GBC estimate is 12% lower than the benchmark figure which is acceptable considering the variability year to year of maintenance estimate.

11.3 Insurance

The following Insurance costs were advised by Global CCS Institute (Global CCS Institute, 2012) for a CCGT + CCS of 742.5 MW net power output (similar to the size of the Generic Business case plant). These costs exclude transportation and storage. The Benchmark has been escalated for inflation from 2010 to 2016 and from the scale of the Benchmark to the size of the GBC so as to be a representative comparison.

Insurance & local taxes	Benchmark	Benchmark £M/annum	GBC Estimate £M/annum	Comments
Insurance & local taxes	2% of total plant cost (Davidson, May 2009) 2% of total plant cost (Summers, Gerdes, & Wimer, August 2011)	35.3	42.3	Insurance costs have been estimated by the GBC project as 20% higher than benchmark, The additional insurance premium for the GBC accounts for transportation and storage in an offshore UK location

Table 20 – Benchmark of Insurance and Taxes

11.4 Chemicals and Consumables

The following Insurance costs were advised by Global CCS Institute (Global CCS Institute, 2012) for a CCGT + CCS of 742.5 MW net power output (similar to the size of the Generic Business case plant). These costs exclude transportation and storage. The Benchmark has been escalated for inflation from 2010 to 2016 and from the scale of the Benchmark to the size of the GBC so as to be a representative comparison.

Variable Costs	Benchmark €/hour	Benchmark £/hour escalated	GBC Estimate £/hour	Comments
Chemicals and Consumables	740	1038	1033	The benchmark, escalated for scale and inflation, shows a close correlation to the GBC work.

Table 21 – Benchmark of Chemical and Consumables Costs

11.5 MMV

The Measurement, Monitoring, and Verification (MMV) estimate has been compared with Benchmark Range used by ZEP (Maas).

	Benchmark €	Benchmark £	GBC Estimate £	Comments
MMV	€0.6 to €1.8 / tonneCO_2	£0.5 to £1.6 / tonneCO_2	£1.6 tonneCO_2	The GBC estimate comparison is the summation of MMV for the 25 years OPEX model vrs 10MTPA CO_2 injected for the period. The summation is used across the 25 years as some years have only a small expenditure and the seismic survey every 5 years is a large cost.

Table 22 – Benchmark of MMV Costs

The GBC estimate is conservative with respect to the MMV costs for the scheme as it has been assumed that the MMV activities would be double the cost for 2 offshore platforms. There is a potential that the costs may be less as mobilisation, sailing time from port to survey area, and reporting costs would be common to the reservoir areas of both platforms.

11.6 Transportation

O&M cost information from the CO_2 Pipeline Infrastructure Report (ECOFYS & SNC-Lavalin, 2014) provides a benchmark for OPEX costs of 1.5% to 8% per year of initial capital costs. The large spread is because the OPEX costs at the higher end include pipeline compression / booster stations within the pipeline operating cost which is not applicable as these are included in the CO_2 Compression and Dehydration section of the GBC estimate. The 8% including pipeline booster stations is aligned with the OPEX estimate from the White Rose Project (Capture Power Limited, 2016). The Global CCS Institute uses 5% for transportation without compression and dehydration (Global CCS Institute, 2011).

The table below shows that the SNC-Lavalin estimate fits within the suggested range.

Fixed Costs	Benchmark	GBC CAPEX Estimate	GBC OPEX Estimate	GBC OPEX
Transportation	1.5% to 8% CAPEX per year	£303,389,214	£12,565,160 (Year 3)	4.1% CAPEX per annum

Table 23 – Benchmark of Transportation

11.7 Offshore Storage

Benchmark of 4% CAPEX per annum has been used by SNC-Lavalin's team for previous project estimates for Offshore Facilities (this includes wells). It is assumed that although this percentage is for offshore production facilities it is representative for injection facilities. This is in line with 4% CAPEX per annum used by ZEP (Maas). A range of 3.3% to 3.6% of CAPEX is used by (Haszeldine & Di Zhou, 2014)

Total OPEX	Benchmark	GBC CAPEX Estimate	GBC OPEX estimate	GBC OPEX
Offshore Storage	4% CAPEX per annum	£444,348,207 (5 Trains)	£13,965,713 (5 Trains, year 3)	3.1% CAPEX

Table 24 – Benchmark of Offshore Storage

The estimate produced by SNC-Lavalin is similar to the benchmark. Some difference was expected in that the GBC facilities are for CO_2 injection and the benchmark is for oil and gas industry production facilities. The oil and gas industry facilities have additional maintenance requirements due to the fire and explosion hazard which is not present in the CO_2 facility. Also, the benchmarks for offshore facilities typically include maintenance for systems associated with helicopter operations which is not the case for the GBC project as the access is through a W2W vessel.

12 O&M Hazards

The Thermal Power with CCS Scheme has a number of hazards associated with the Operation and Maintenance activities which are outlined in this section. This section is designed to communicate the hazards to future phases of the project, and to inform aspects of the O&M planning which may influence the cost estimate.

Carbon Dioxide (CO_2)

Danger to life from asphyxiation or toxicity of escaping CO_2

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)

Maintain and test the CO_2 detection, alarm, isolation, and blow down 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)

Train and practice emergency response drills and evacuation procedures

Natural Gas

Danger to life from the explosion of escaping natural gas

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

Regularly maintain and test fire protection system

Train and practice emergency response drills and evacuation procedures

HV / MV / LV Electricity

Hazard from an electric shock when working on electrical systems

This may result in fatality

- Electrical supplies shall be isolated and locked off before work commences
- HV Electrical systems shall be fenced off to prevent unauthorised or uncontrolled access
- 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

Noise

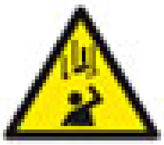
Hazard resulting from exposure to noise from activities such as venting and running machinery.

This may result in hearing damage.

- Personal Protective Equipment shall be worn! Hearing protection
- Notices shall be clearly visible to warn personnel of Hazard
- Routine noise surveys to be carried out to ensure noise levels have not increased
- Health of workers exposed to hazard areas to be monitored

 	**High Temperatures** Hazard resulting from hot surfaces such steam pipe work. Potential for HP steam release in the Power Generation Plant. This may result in burns › Training required for all personnel working in areas with HP steam and condensate pipe work › Personal Protective Equipment shall be worn! Gloves › Avoid touching hot surfaces › Insulation and personnel barriers to be maintained › Steam traps to be regularly services to ensure condensate does not build up in systems






Falling Objects

Hazard resulting from falling objects when working with loads!

This may cause personal injury.

- Risk assessments, method statements and lifting plans shall be produced by a competent person for all major lifts.
- Use unimpaired lifting gear of adequate carrying capacity. Lifting equipment shall be properly maintained, adhere to site colour coding rules and maintenance certificates shall be recorded in a site log. All lifting equipment and tackle shall be inspected before use.
- Maximum lift weight must be known.
- Training shall be provided regarding the correct method of reading lifting capacity charts for chain slings, wire ropes and webbing slings.
- Riggers, Slingers, Signalmen, Crane Operators, persons in charge of lifting operation (PICOLO) and Supervisors shall be trained (e.g. to BS 7121).
- Never step beneath suspended loads. Areas under the lift shall be controlled by the banksman. Banksmen must wear high visibility jackets/vests and have whistle. Barriers, warning signs and warning tape shall be used to prevent unauthorised access.
- Personal Protective Equipment shall be worn! Hard hat and safety boots.
- High visibility clothing to be worn to increase visibility of personnel to crane operator.





Chemicals

Hazard resulting from contact with chemical agents used for systems such as water treatment and boiler feed water.

This may lead to poisoning or chemical burns.

- Only qualified personnel shall work with chemicals and chemical systems
- All COSHH and chemical agent material safety datasheets (MSDSs) shall be available and associated hazards reviewed with personnel involved with the operation
- Personal Protective Equipment shall be worn when handling chemicals! Eye protection, chemical resistant gloves, chemical resistant boots and chemical resistant overalls
- All chemicals shall be neutralised or disposed of in accordance with the sites environmental impact policy
- Eye wash bottles/station to be present
- Showers to be present

An inventory of hazardous substances forms an Attachment to the Detailed Report: Plant Performance and Capital Cost Estimating, document reference 181869-0001-T-EM-REP-AAA-00-00004 (ETI Ref: D4.1).

High Pressure

Danger to life from the release of high pressure

Maintain design records of pressure systems, operating instructions, operating and maintenance manuals

Competent and trained personnel only to work on high pressure systems

Maintain written scheme of examination for pressure systems

Work on pressure systems to be controlled (e.g. permit to work system)

Pressure systems to be maintained and inspected

Pressure systems to be depressurised before invasive works carried out

Retest of pressure systems after works carried out

	**Offshore** Danger to life from drowning Personnel working offshore to be trained in offshore survival Risk is reduced by substitution of helicopter travel with marine travel Maintenance visit planning required to meet weather windows for work Emergency planning to be in place in case of transport accidents Emergency refuge to be located on offshore facility in case W2W vessel cannot remain in attendance Gear and PPE to be suitable for marine conditions

	Weather Danger to health from inclement weather CCGT + CCC onshore plant is a large facility which does not have many refuges within the design Clothing and PPE to be suitable for weather conditions Operations and maintenance activities to be planned taking weather into account Rest and water to be provided for workers in hot conditions

	**Traffic** Danger to life from road traffic accidents CCGT + CCC onshore plant is a large facility which will need many traffic movements during the life of the plant Pedestrians and road users to be segregated Speed limits to be enforced

	Drivers to be competent Drug and alcohol policy in place for site workers Banksmen to be employed for manoeuvres Movements to be planned to eliminate reversing if possible. Vehicles to be fitted with audible and visual warnings for reversing

	Terrorism Danger to life from acts of terrorism Terrorism – the 3 to 5 train sites would be a large strategic target Security in design – entrance protected. May need natural defences (ditches, berms, landscaping, double fencing, if facility has exposed areas) Capital cost estimate includes guardhouse, ACS, CCTV, Telelcomms, crash escape gates, isolations, etc for security) Security personnel to be provided for the site: sufficient for threat level Personnel to be trained in action to take in response to a threat or attack Management to take advice from the Police service

13 Conclusions

Operation

The Power Generation facilities are expected to operate at base load or high load factors with the number of starts and stops minimised. The CCS chain does not operate well in cyclic or start / stop operation. This does limit the flexibility of a Thermal Power with CCS scheme. However, the scheme has sufficient flexibility to operate alongside nuclear and offshore wind generation, and to be switched off ahead of these generation sources should generation exceed demand.

There is some operational flexibility within the plant because each train within the scheme can be turned down to ~50% of its maximum output and if there is more than one train then some trains can be shut down whilst others continue to operate and deliver CO_2 for injection and storage.

Maintenance

The maintenance schedule is dictated by the CCGT gas and steam turbines: the remainder of the CCS scheme can fit in with this schedule.

Campaigning major maintenance train by train as might be done per power industry practice potentially exposes a large maintenance population to the risks associated with high pressure CO_2. The operating scenarios set out in this report assume that the whole plant be shut down for major maintenance to avoid these risks, but it is recognised that this approach may be challenging from a commercial perspective.

Annual OPEX Costs

OPEX costs vary year on year depending on the amount of operation and the maintenance tasks that are scheduled.

The OPEX costs are dominated by the fuel gas costs: approximately 65% of total OPEX costs are fuel gas at 50.1p/therm. A sensitivity analysis has been carried out to see what the impact of variations in fuel price will have on the overall OPEX costs. +/- 10p/them has a +/- 13% impact on the overall fuel costs.

Insurance costs dominate the fixed cost estimate.

The maintenance costs are dominated by the offshore maintenance for which the 4D seismic survey (part of the MMV) is the largest component.

Costs have been estimated for hot, warm, and cold starts which show that there is a significant cost for cold starts because of the time taken to start injecting CO_2 into the well from the start of the CCGTs: assuming that revenue cannot be earned against a CfD until the plant has reached abated operation each cold start will cost approximately £0.5M. This reinforces that a mode of operation with frequent stops and starts is not preferred to baseload operation.

For the purposes of this OPEX estimate, it has been assumed that the scheme will run at full base load, i.e.) whenever the scheme is not down due to planned or forced outages, it operates at 100% load. No degradation or performance upgrades in performance have been assumed.

Number of Trains

The OPEX model produced by the project team shows that there is some improvement in the OPEX estimate per kW between the different size plants: this is shown in the following table. This table is based on a north east England location.

OPEX Costs	1 Train	2 Train	3 Train	4 Train	5 Train
£ / kW / year	£417	£390	£382	£381	£377
£ / MWhr	£50	£47	£46	£46	£45

Table 25 – OPEX Estimate per kW – Year 4

Regions

Regional differences in operating costs are minimal with the exception of additional offshore consumables, maintenance, and monitoring costs for the addition of a second platform for the North East regions for 4 and 5 trains and Scotland for 2 and 3 trains. An additional platform would result in increased consumables of £510,000 annually, and increased maintenance and inspection costs of £35 million.

Small differences may exist for utility costs or wayleave costs; however, this nuance has a negligible impact on the overall operating costs. Labour costs may also vary slightly between regions. A 5% increase in total labour costs would result in a 0.15% increase in OPEX for a single train plant.

Abandonment

The decommissioning and abandonment costs have been estimated. These show that the abandonment costs for the Northwest/North Wales region is lower than the North East of England regions because the maximum plant size is smaller (3 trains compared to 5) and because there is only one offshore facility to abandon compared to two platforms for 4 or 5 train size plant over the Endurance Aquifer.

Scotland has a proportionally higher Abandonment cost compared to the North East of England regions as the cost is higher and the comparison is for two less trains at the Scotland onshore site. The higher cost for the Scotland region is due to the cost of abandoning two offshore platforms which are installed in deeper water.

No. Trains	5 Trains	5 Trains	5 Trains	3 Trains	3 Trains
Area	**Teesside**	**North Humber**	**South Humber**	**Northwest / North Wales**	**Scotland**
Total Cost (£m)	**£271**	**£267**	**£267**	**£132**	**£251**

Table 26 – Abandonment Cost per Region

14 Abbreviations

The following abbreviations have been used in this document:

Abbreviation	Description
AACE	Association for the Advancement of Cost Engineering
ABEX	Abandonment Expenditure
ACS	Access Control System
AGI	Above Ground Installation
ALARP	As Low As Reasonable Practicable
BEIS	Department for Business, Energy and Industrial Strategy
BS	British Standard
BSUoS	Balancing Services Use of System
C&I	Control and Instrumentation
CAPEX	Capital Expenditure
CC	Carbon Capture
CCC	Carbon Capture and Compression
CCGT	Combined Cycle Gas Turbine
CCS	Carbon Capture and Storage
CCTV	Closed Circuit Television
CfD	Contract for Difference
CHP	Combined Heat and Power
CO_2	Carbon Dioxide
COSHH	Control of Substances Harmful to Health
DCC	Direct Contact Cooler
DECC	Department of Energy and Climate Change (now BEIS)
EHS	Equivalent Hot Starts
EOH	Equivalent Operating Hours
EPC	Engineering, Procurement, and Construction
ETI	Energy Technologies Institute
GBC	Generic Business Case

Abbreviation	Description
HAZID	Hazard Identification Study
HAZOP	Hazard and Operability Study
HP	High Pressure
HRSG	Heat Recovery Steam Generator
HSSE	Health Safety Security and Environmental
HV	High Voltage
ICSS	Integrated Control and Safety System
IT	Information Technology
KKD	Key Knowledge Documents
LCOE	Levelised Cost of Electricity
LLP	Limited Liability Partnership
LOLER	Lifting Operations and Lifting Equipment Regulations
LV	Low Voltage
MMV	Measurement, Monitoring, and Verification
MSDS	Material Safety Data Sheet
MTPA	Million Tonne Per Annum
MV	Medium Voltage
O&M	Operations and Maintenance
OCGT	Open Cycle Gas Turbine
OEM	Original Equipment Manufacturer
OFGEM	The Office of Gas and Electricity Markets
OPEX	Operating Expenditure
PICOLO	Persons in Charge of Lifting Operation
PPE	Personal Protective Equipment
QC	Quality Control
TNUoS	Transmission Network Use of System
TSR	Temporary Safe Refuge
UK	United Kingdom
USA	United States of America
VAT	Value Added Tax
W2W	Walk to Work

Abbreviation	Description
ZEP	Zero Emissions Platform

Table 27 – Abbreviations

15 References

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Photos Appearing In The Text

Front Cover	Photomontage of the GBC Project developed by AECOM for the ETI.
Executive Summary	Newark Energy Center http://www.snclavalin.com/en/projects/newark-energy-center
Structure of the Report	Southcentral Power http://www.snclavalin.com/en/southcentral-power-plant
Plant Operating Scenario Basis	Cygnus http://www.snclavalin.com/en/cygnus-jacket
Estimate Assumptions	Emal CCGT – image from SNC-Lavalin brochure for Asia Pacific Energy Solutions
Benchmarking	ICSS – Saskatchewan http://www.snclavalin.com/en/training-program-for-iccs
References	Kings North 36" Pipeline http://www.snclavalin.com/en/kings-north-connection

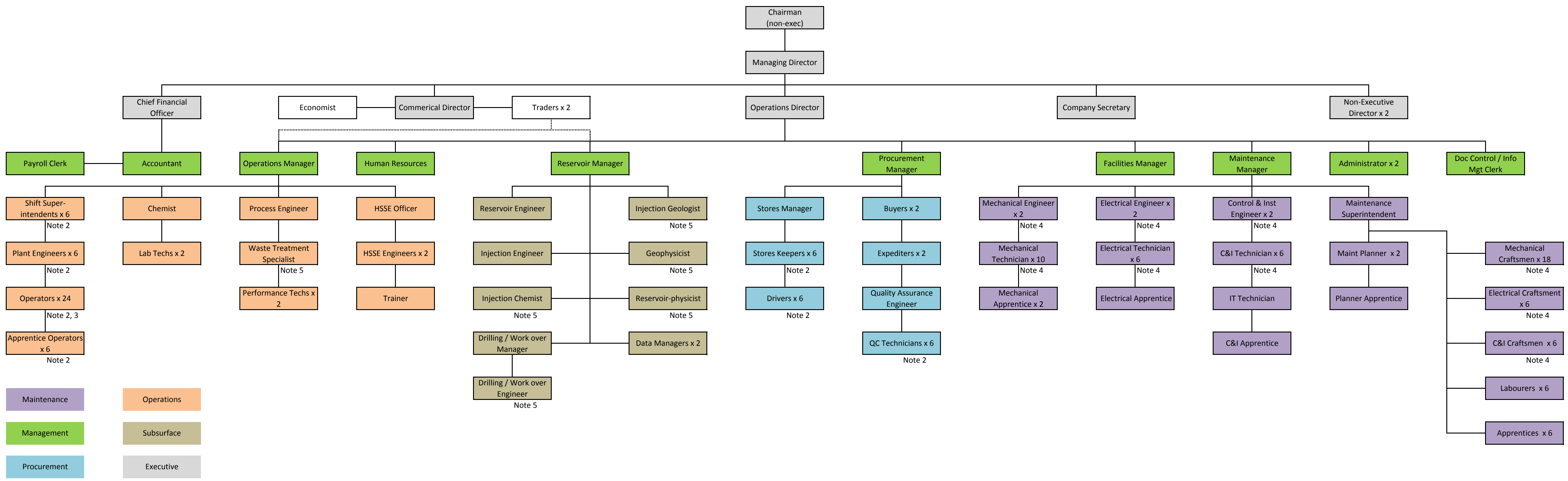
Table 28 – Images Appearing in the Document

Acknowledgements

The authors would like to thank Shell UK Limited who provided permission for SNC-Lavalin to use data from the Peterhead CCS Proposal in support of this report.

Attachment 1 – Operations Team Organisation Chart

OPERATIONS AND MAINTENANCE TEAM FOR THE CCGT + CCS SCHEME



Shift Pattern Calculation:		
Days per week	7	
Hours per day	24	
Weeks per year	52	
Hours per year	8736	
Hours per Shift	10	(Allow 12 hours with 2 for handover)
Total Shifts	874	Per year
Annual Leave	25	days per year
Bank Holidays	8	per year
Approx per year	7	weeks
Max Hours	48	hours per week
Shifts per week	4	
Max Shifts / year	180	(above - annual leave)
Needed Teams	5	
Added for O/S	1	Note 2
Total Shifts	6	

NOTES

1. Sources of Information
   - a) K20 Project Implementation Phase project execution plan, Capture Power Limited
   - b) Central Power Plant (CPP) University Central and Medical Campuses
   - c) Benchmarking Data, 181869-0001-T-PC-CAL-AAA-00-00001
   - d) PCCS-00-PTD-OA-5522-00001, Operation and Maintenance Philosophy. Revision: K02

2. Shifts: 6 shift pattern working 12 hour shifts to cover the overall scheme
   Operators and Maintenance Personnel from the team will be schedule to visit the Offshore Platform
   Pipeline AGIs are assumed to be un-manned: O&M team to provide away teams for scheduled and unscheduled visits to AGIs.

3. Operators will run entire CCGT + CCS scheme from the Control Room
   - 1 Operator = CCGT
   - 1 Operator = CCC
   - 1 Apprentice Operator = Utilities
   - 1 Operator = Transport & Storage

4. Day shift - on call rota for nights and weekends

5. Part Time Consultant

Attachment 2 – Maintenance Routine

Maintenance Routine

	Activity	Frequency	Duration	Outage	Comments
Power Generation					
Power Generation	Initial Inspection	1000 hrs	21 days	21 days	
Power Generation	Gas Turbine Combustion Inspection (note 11)	8000 hrs	10 days	7 days	
Power Generation	HRSG Internal Inspection (note 11)	8000 hrs	5 days	See above	
Power Generation	Generator Inspection (note 11)	8000 hrs	1 day	See above	Requires disconnect of machine in order to carry out preventative maintenance
Power Generation	Steam Turbine Minor Inspection	16,000 hrs	2 days	2 days	
Power Generation	Generator Inspection	16,000 hrs	2 days	See above	Machine disconnected to allow diagnostics onto electrical terminals
Power Generation	Gas Turbine Hot Gas Path Inspection	24,000 hrs	40 days	35 days	
Power Generation	Generator Internal Inspection	24,000 hrs	5 days	See above	
Power Generation	Gas Turbine Major Inspection / Overhaul	48,000 hrs	57 days	49 days	
Power Generation	Steam Turbine Major Inspection	48,000 hrs	21 days	See above	
Power Generation	Generator Rotor Removal Inspection	48,000 hrs	10 days	See above	
Power Generation	Steam Turbine Overhaul	100,000 hrs	57 days	49 days	
Carbon Capture					
Carbon Capture	In General - will follow the maintenance routine set by the Power Generation Unit				
	KEY EQUIPMENT ITEMS				
Carbon Capture	Blower	Same as compressor			Same as Compressor
Carbon Capture	Process Licensor	8000 hrs	14 days		Assume 100 hours support each year for Amine Circuit. Majority of payment to licensor is up front licence fee and surcharge on Amine Solvent.
Carbon Capture	CO_2 Compressor	720 hours	1 day		Checking automatic cut-in of the auxiliary and emergency oil systems Draining condensed water and oil sludge from the oil reservoir Servicing the filter elements Checking the leakage current arrestor
Carbon Capture	CO_2 Compressor - oil sampling and lab analysis	500 hours	1 hour		
Carbon Capture	CO_2 Compressor - external inspection	8,000 hrs	5 days		Duration includes OEM report write up
Carbon Capture	CO_2 Compressor - internal inspection	24,000 hrs	5 days		
Carbon Capture	CO_2 Compressor - overhaul	48,000 hrs	10 days		Replacement of Bearings and Seals
Carbon Capture	Dehydration Package - Mole Sieve Replacement	24,000 hrs	5 days		
Utilities	Waste Water Treatment Plant - Membrane Replacement 1	16,000 hrs			
Utilities	Waste Water Treatment Plant - Membrane Replacement 2	40,000 hrs			
Utilities	ICSS	24,000 hrs			
Transport					
Transport	Onshore Route Survey	340 hrs	1 day		
Transport	Cathodic Protection Survey	8,000 hrs	1 day		
Transport	Emergency Systems Check	8,000 hrs	1 day		
Transport	Offshore Route Survey (side scan sonar)	40,000 hrs	7 days		
Transport	Internal Inspection (Intelligent Pig Run)	40,000 hrs			
Transport	Overpressure Protection Devices	8,000 hrs	1 day		Typically PSVs are twinned and interlocked so that 1 can be removed for calibration without stopping plant operation. Shutdown is only required for test of automation systems and mechanical maintenance to valves.
Transport	Population Density Survey, Review of any Sensitive Proposed New Sites (e.g. Schools)	16,000 hrs	28 days		
Transport	Cathodic Protection Rectifier Maintenance	1,350 hrs	1 day		
Transport	Valve Maintenance and Inspection	4,000 hrs			
Transport	Leak test	40,000 hrs			Schedule with Intelligent Pig Run.
Offshore					
Offshore	Campaign Maintenance Visits	1,350 hrs	8 days		Six campaign maintenance visits per year of 6-8 days duration with a crew of 12 (planned and unplanned maintenance c. 6000 manhours per year); additional visits for ad-hoc work
Offshore	Well Washing	8,000 hrs per well	7 days		Only the well being washed is shutdown. Injection to continue with operating wells. Spare well provided for each platform.
Offshore	Wireline logging suite (incl PNT, density, sonic, well bore integrity etc)	80,000 hrs			Gather data on the reservoir, overburden and wellbore to reservoir models. Assume £50k/time - 2 times (after 10 year and after 20 years - wells re-drilled after ~ 15 years so will have wireline suite then)
Offshore	Heavy Work Over	120,000 hrs			Intervention only required following failure within well.
Monitoring					
	DURING OPERATION				
Monitoring	4D seismic survey	40,000 hrs			For detection of any migration outwith storage site Data Source: PGS Assume survey cost per time - 4 times (after 5, 10, 15, 20)
Monitoring	Chirps, boomers & pingers; sidescan sonar	40,000 hrs			Looking to detect any bubble streams around abandoned wellheads, seabed or pock-marks. Data Source: IEAGHG Assume £100k/time - 4 times
Monitoring	Seabed sampling, ecosystem response monitoring, geochemical analyses of water column	40,000 hrs			Looking to detect any evidence of elevated CO2 concentrations in sediment or water column which may indicate loss of containment. Data Source: IEAGHG Assume £50k/time - 4 times
Monitoring	DTS, downhole and wellhead P/T gauge and flow meter readings	Continuous			Temperature, pressure and flow data to ensure injection integrity and update reservoir models.
Monitoring	Data management	Continuous			To collate, manage, interpret and report on monitoring data.

Notes:

1. Sources of Information:
   - CO_2 Pipeline Infrastructure, Report 2013/18, IEAGHG
   - Single-Shaft Combined-Cycle Power Generation System, Tomlinson and McCullough, GE Power Systems (GER-3767C)
   - PCCS-00-PT-AA-7704-00001, Basis of Design for the CCS Chain, Shell UK Limited
   - PCCS-00-PTD-AA-7704-00002, Basic Design and Engineering Package, Shell UK Limited
   - PCCS-00-MM-FA-3101-00001, Cost Estimate Report, Shell UK Limited

2. Key
   - SHUT DOWN REQUIRED (hatched)
   - DOES NOT INTERFERE WITH OPERATION (dotted)

3. Steam Turbine Operating Hours for Scheduled Maintenance assumes 80 normal starts per annum.

4. Included in drilling costs.

5. Included in well costs.

6. Included in O&M staff costs.

7. Three years after installation or overhaul.

8. Assumption that general valves, pumps, static equipment, etc would be serviced by O&M personnel using OEM manuals and training.

9. Outage Column is time off bars (not generating). This excludes set up, knock down, and reporting time.

10. Assumption that content in Power Generation and Carbon Capture is for OEM Subcontracts.

11. Annual outage would be staggered; individual trains to be shut down 1 at a time.

Attachment 3 – Utility Schedule

UTILITIES SCHEDULE

Document No: **181869-0001-T-EM-LST-AAA-00-00001**

1 OF 16

Revision **: A03** Date **: 02-JUN-2017**

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: T072923.

A03	02-JUN-2017	Updated for OPEX Estimate	M. WILLS	K.SREENIVASAN	S. DURHAM	M. WILLS
A02	27-APR-2017	Issued for CAPEX Estimate	M. WILLS	T. ALI	S. DURHAM	M. WILLS
A01	29-MAR-2017	Issued for Internal Review	M. WILLS	T. ALI	S. DURHAM	M. WILLS
REV	**DATE**	**ISSUE DESCRIPTION**	**BY**	**DISC CHKD**	**QA/QC**	**APPVD**

Disclaimer

REVISION	COMMENTS
A01	Issued for Internal Review
A02	Issued for CAPEX Estimate
A03	Updated for OPEX Estimate Changes in Red Colour

HOLDS	
HOLD DESCRIPTION / REFERENCE	
<HOLD 1>	Deleted
<HOLD 2>	Deleted
<HOLD 3>	Deleted
<HOLD 4>	Deleted

1. Factoring for Shell Peterhead - refer to 181869-0001-T-EM-CAL-AAA-00-00004 rev A02 and 181869-0001-T-EM-TNT-AAA-00-00010 rev A05

CO_2 and Amine Ratio

Flow or Power Ratio	1.66

Flue Gas Ratio

Flow or Power Ratio	1.35

2. Information source for the carbon capture and compression utility consumption is:
Utility Requirement Report/Utility Summary Capture & Compression
PCCS-02-TC-PX-7180-00005 rev K01
The Peterhead utility consumption had 10% to 20% margin added - this has not been included in this document.

3. Electrical loads can be found in the Major Equipment List
181869-0001-T-ME-MEL-AAA-00-00001

4. These figures are 'per Train' unless otherwise labeled.

Unit	User (LP Steam) Per Train	Pressure	Temp In	Temp Out	Normal	Intermittent	
		bara	ºC	ºC	kg/hr	kg/hr	
Power	Steam Turbine	2.4	130		-	2,000	Note 1
Carbon Capture	Utility Station	2.4	130		-	332	
Carbon Capture	CO_2 Stripper Reboilers - Steam Heating	2.4	138.7	126.1	299,904	-	
Carbon Capture	Steam Sparger Condensate Pot - Steam Heating	2.4	130		33	-	
Carbon Capture	LP Steam (From MP Condensate =15.66 %)	2.4	138.7	126.1	- 2,103	-	Note 2
				Total	297,834	2,332	

NOTES:
1. Steam supply for start-up, shutdown, and standby.
2. Steam flashed from MP Condensate in piping special flash pot within Carbon Capture Unit
   Flash fed to LP Steam Header for cunsumption in Carbon Capture Unit
   Flash steam deducted from LP Steam demand from Power Generation Plant

Unit	User (MP Steam) Per Train	Pressure	Temp In	Temp Out	Normal
		bara	ºC	ºC	kg/hr
Carbon Capture	Thermal Reclaimer No 1 reboiler	21.06	215	215	5,397
Carbon Capture	Thermal Reclaimer No 2 reboiler	21.06	215	215	554
Carbon Capture	Thermal Reclaimer No 3 reboiler	21.06	215	215	926
Carbon Capture	CO_2 Vaporiser	21.51	235	215	6,552
				Total	13,429

Unit	User (Condensate Balance) Per Train	Q (norm) kW	Pressure bara	Temp In ºC	Temp Out ºC	Normal kg/hr	
Produced							
Carbon Capture	LP Condensate		2.4	138.7	126.1	297,834	
Carbon Capture	MP Condensate		21.06	235 / 215	215	13,429	
LP Condensate Users							
Carbon Capture	LP Steam (From MP Condensate =15.66 %)		2.4	215	138.9	2,103	Note 1
Carbon Capture	Thermal Reclaimer No.1 Pre-Heater	226	6	129.9	49.5	3,534	
Carbon Capture	IX Demin Water Heater	52	6	129.9	49.5	430	
Carbon Capture	Condensate Cooler	28718	8.5	129.9	49.5	305,196	

NOTES:

1. Steam flashed from MP Condensate in piping special flash pot within Carbon Capture Unit
   Flash fed to LP Steam Header for cunsumption in Carbon Capture Unit

Unit	User (Towns Water) Per Train	Pressure bara	Temp In ºC	Temp Out ºC	Normal kg/hr	Rated kg/hr	Start Up kg/hr	
Carbon Capture	Degraded Product Tank				281	3,320		
Carbon Capture	Degraded Amine Sump Drain Sump						3,320	
Carbon Capture	Direct Contact Cooler						-	Note 6
Carbon Capture	Vacuum Package				3,320	4,980		
Carbon Capture	Vacuum Package				3,320	4,980		
Carbon Capture	Chemical Sewer Tank					3,320		
Cooling Water	Closed Loop Cooling Water System						-	Note 6
Facilities	Potable Water				2,400	2,400	2,400	Note 7
Facilities	Towns Water Hose						4,000	
Facilities	Utility Stations					8,640		Note 3
Facilities	Safety Showers					29,964		Note 5
				Total	9,321	57,604	9,720	

NOTES:
1. Potable Water supply taken from Towns Water supply at Battery Limit (no break tank).
2. Via Towns Water Break Tank, T-002.
3. Four utility stations, rated at 120%.
4. Service Water taken from Towns Water supply at Battery Limit.
5. Four safety showers in operation, rated at 110%.
6. DCC and Cooling Water Circuit make up from Raw Water.
7. Potable Water Consumption based on 100 L / day / person based on site manning of 120 people
For calculation this becomes 24 people per train
Refer to 181869-0001-T-EM-REP-AAA-00-00005, Attachment 1.
8. Plant Supply line sizing for 1.5 m/s minimum velocity (normal flow for 5 trains + 20% to top up Tank) 5 inch

Unit	User (Raw Water) Per Train	Pressure	Temp In	Temp Out	Normal	Start Up	
		bara	ºC	ºC	kg/hr	kg/hr	
Carbon Capture	Degraded Product Tank						
Carbon Capture	Degraded Amine Sump Drain Sump						
Carbon Capture	Direct Contact Cooler					18,260	
Carbon Capture	Vacuum Package						
Carbon Capture	Vacuum Package						
Carbon Capture	Chemical Sewer Tank						
Cooling Water	Closed Loop Cooling Water System				1,731,052	-	Note 1
Utilities	Demin Water Package				30,133	71,048	Note 2
				Total	1,761,185	89,308	
				Total (5 Trains)	8,806	Te/hr	

NOTES:
1. Make up water from Cooling Water Sheet
2. Demin Water Package demand from Demin Water table.
   Additional flow added for backflush within package (7%).

Unit	User (Demin Water) Per Train	Pressure bara	Temp In ºC	Temp Out ºC	Normal kg/hr	Rated kg/hr	Start Up kg/hr	
Power	Steam Circuit				635	635		Note 1
Power	Auxiliary Boiler						16,200	Note 3
Carbon Capture	Thermal Reclaimer Column No. 1					1,660		
Carbon Capture	Thermal Reclaimer Column No. 2					216		
Carbon Capture	Thermal Reclaimer Column No. 3					3,486		
Carbon Capture	Lean Amine Tank					33,200	33,200	
Carbon Capture	Fresh Amine Tank					33,200	33,200	
Carbon Capture	Amine Drain Tank					8,300		
Carbon Capture	CO_2 Absorber Water Wash Loop					24,830		
Carbon Capture	Acid Water Wash Loop				274	299		
Carbon Capture	Demin Water Heater				27,888	89,640		Note 2
Carbon Capture	Thermal Reclaimer Unit Bottoms					1,660		
				Total	28,162	89,640	66,400	

NOTES:

1. From Water Accounting in GTPro Modelling, Page 50, Attachment 1, 181869-0001-T-EM-TNT-AAA-00-00010.

2. Demin Water Heater feeds the Caustic System for effluent treatment

3 Value based on PCCS-01-TC-PX-7180-00005.

Unit	User (Cooling Water) Per Train	Normal Duty	Pressure	Temp In	Temp Out	Normal	
		kW	bara	ºC	ºC	kg/hr	
Power Generation	Rankine Cycle Condensers	367,574	4	13	23	31,581,537	Note 3
Power Generation	Gas Turbine Water Coolers	1,810	4	13	23	155,470	Note 5
Power Generation	GT Generator Water Coolers	8,617	4	13	23	740,334	Note 5
Power Generation	Steam Turbine Water Coolers	840	4	13	23	72,172	Note 5
Power Generation	ST Generator Water Coolers	4,000	4	13	23	343,675	Note 5
Carbon Capture	DCC Water Coolers	96,391	4	13	23	8,281,820	Note 4
Carbon Capture	Water Wash Cooler	77,269	4	13	23	6,638,880	Note 4
Carbon Capture	Lean Amine Cooler	24,593	4	13	23	2,112,994	
Carbon Capture	IX Amine Cooler	276	4	13	23	23,676	
Carbon Capture	Thermal Reclaimer No. 1 Condenser	2,689	4	13	23	231,053	
Carbon Capture	Thermal Reclaimer No. 2 Condenser	272	4	13	23	23,391	
Carbon Capture	Thermal Reclaimer No. 3 Condenser	606	4	13	23	52,058	
Carbon Capture	Overhead Condensers	51,986	4	13	23	4,466,596	
Carbon Capture	Regeneration Gas Discharge Cooler	2,932	4	13	23	251,876	
Carbon Capture	Compressor Package	38,658	4	13	23	3,321,458	
Carbon Capture	5th Stage Compressor Outlet Cooler	9,744	4	13	23	837,211	
Carbon Capture	Condensate Coolers	28,653	4	13	23	2,461,855	
Utilities	Instrument Air Compressor Package	65	4	13	23	7,208	Note 6
		716,974			Total	61,603,264	

NOTES:

1. Basis of Design Cooling Water Temperatures are 13 to 23ºC.
   10ºC delta T is the same as Peterhead design: however, design used different temperatures.

2. Make up water is estimated to be 2.81% of flow (loses for evaporation and drift) 1,731,052
   493.55 kg/hr of 17592.42 kg/hr (page 32 of Attachment 1 to 181869-0001-T-EM-TNT-AAA-00-00010).

3. Thermal duty taken from 181869-0001-EM-TNT-AAA-00-0010, Rev A01, Attachment 1 Page 32

4. Was on seawater. Scale for Flue Gas Ratio.

5. Vendor Data for Similar Steam Turbine.
   Scaled up for Gas Turbine size from Steam Turbine data.

6. Scaled up to include CCGT.

Unit	User (Fuel Gas) Per Train	Pressure bara	Temp ºC	Rated Nm^3/hr	Intermittent Nm^3/hr	
Power Generation	Gas Turbine Fuel	65	20	113,400	-	Note 1
Power Generation	Auxiliary Boiler	65	20	-	2,430	Note 2
			Total	113,400	2,430	
			Total (5 Trains)	567,000		

NOTES

1. Fuel gas consumption from 181869-0001-T-EM-CAL-AAA-00-00007.

2. Scale up from PCCS-01-TC-PX-7180-00005.

Unit	User (Instrument Air) Per Train	Pressure bara	Temp In ºC	Temp Out ºC	Normal Nm^3/hr	Rated Nm^3/hr	Intermittent Nm^3/hr	
Power	All Users	8	Amb			2,097		Note 8
Carbon Capture	Control Valves	8	Amb		93	102		Note 1
Carbon Capture	On/off Valves	8	Amb		2	3	23	Note 2
Carbon Capture	Analysers (Oxygen, Chromatograph)	8	Amb		60	65		Note 3
Carbon Capture	Analysers (moisture, pH, CO_2, water, emission)	8	Amb		65	71		Note 4
Carbon Capture	Louvers / Dampers	8	Amb		77	84		Note 5
Carbon Capture	CO_2 Compressor	8	Amb		415	457		Note 7
Carbon Capture	Ion Exchange Package	8	Amb		249	274		Note 7
Water Treatment	Effluent Treatment Package	8	Amb		52	57		Note 7
				Total	1,012	3,210	23	Note 6, 8

NOTES:
1. Based on 62 control valves. Instrument air consumption is considered as 1.5 Nm3/hr for each control valve.
2. Based on 46 on/off valves with 2 valves in operation at any one time. Instrument air consumption is considered as 0.5 Nm3/hr for each on/off valve
3. Based on 7 analysers. For analysers, instrument air consumption is 8.5 Nm3/hr. Peak = 110% of normal flow
4. Based on 19 analysers. For analysers, instrument air consumption is 3.4 Nm3/hr. Peak = 110% of normal flow
5. Based on 9 dampers. For analysers, instrument air consumption is 8.5 Nm3/hr. Peak = 110% of normal flow
6. Rated flow based on 110% of normal flow design margin.
7. Continuous flow contains 125% design margin, to account for preliminary package consumption figures.
8. Based on similar sized CCGT Plant.

Unit	User (Plant Air) Per Train	Pressure bara	Temp In ºC	Temp Out ºC	Normal Nm^3/hr	Rated Nm^3/hr	Intermittent Nm^3/hr	
Power Generation	Utility Stations	8	Amb				255	Note 1
Power Generation	All Users	8	Amb				771	
Carbon Capture	Utility Stations	8	Amb				255	Note 1
Facilities	Maintenance Workshop	8	Amb				100	
				Total	-	-	1,381	

NOTES:
1. Plant air assumes 3 utility stations operating simultaneously (at 85 Nm3/h)

Unit	User (HYDROGEN) Per Train	Pressure bara	Temp In ºC	Temp Out ºC	Normal kg/hr	Rated kg/hr	Start Up kg/hr	
Power Generation	Gas Turbine Generator Cooling	5.2			0.23		85	Note 1,2,3
				Total	0.23	-	85	

Unit	User (NITROGEN) Per Train	Pressure bara	Temp In ºC	Temp Out ºC	Normal kg/hr	Rated kg/hr	Start Up kg/hr	
Power Generation	Purging				Negl	Negl	203	Note 4
Carbon Capture	Pump Seals				Negl	Negl		
Carbon Capture	Sample Connections				Negl	Negl		
				Total	-	-	203	

Unit	User (CO_2) Per Train	Pressure bara	Temp In ºC	Temp Out ºC	Normal kg/hr	Rated kg/hr	Start Up kg/hr
Power Generation	Gas Turbine Fire Fighting					2899	
				Total	-	2,899	-

NOTES:
1. Hydrogen is used to cool the Turbogenerator windings.
   Consumption from reference: "Operation & Maintenance of Large Turbogenerators", Klempner & Kerszenbaum, Wiley, ISBN 0-471-61447-5 and "Adaquate Cooling of Generators is Essential", Smith, Power Engineering Magazine, January 2002.
2. Steam Turbine driven generator is < 300 MW and therefore is air cooled.
   Recent project confirms this assumption.
3. Start up hydrogen usage is for a complete fill of the generator.
4. Start up nitrogen usage is for a purge of the natual gas system.

Unit	AMMONIA Per Train	Pressure bara	Temp ºC	Unabated kg/hr	Abated kg/hr
Power Generation	Selective Catalytic Reduction			-	302
			Total	-	302

NOTES:
1. Published NOX value for class H CCGT = 25 ppmv (GEA32220)
   Environmental Basis for NOX is a limit of 50 ppmv (181869-0001-T-EM-DBS-AAA-00-00001)
   Therefore in unabated operation SCR amine consumption will be zero
   In abated operation NOX to be reduced to 1ppmv to meet requirements of Engineered Solvents Suppliers

2. Ammonia content of solution = 20% to 25%.

3. Based on 21g/sec NH_3.

Unit	LUBE OIL Per Train	Pressure bara	Temp ºC	Normal ltr/hr	Intermittent ltr/hr
Power Generation	Gas Turbine	n/a	n/a	0.67	
Power Generation	Steam Turbine	n/a	n/a	0.30	
Power Generation	Machinery	n/a	n/a	0.09	
Carbon Capture	CO_2 Compressor	n/a	n/a	1.60	
Carbon Capture	Booster Fan	n/a	n/a	0.01	
Carbon Capture	Machinery	n/a	n/a	0.09	
			Total	2.77	-

Unit	HCl Per Train	Pressure bara	Temp ºC	Normal Tonne / yr	Intermittent Tonne / yr	
Power Generation	Demineralisation Package				3	Note 1
			Total	-	3	

NOTES:
1. Based on 448 m^3/hr demin water

Unit	AMINE Per Train	Pressure bara	Temp ºC	Normal Tonne / yr	Intermittent Tonne / yr	
Carbon Capture	Fresh Amine Tank	Atm	Amb	1,589		Note 1-4
			Total	1,589	-	

1. Base consumption from design and Operation Optimisation of a MEA-based CO_2 Capture Unit, Artur Andrade, November 2014.
2. Solvent degradation of engineered solvent is only 10% MEA (IEAGHG).
3. Amine Degradation, Davis & Sexton, Uni of Texas at Austin.
4. Amine inventory per train from 181869-0001-T-EM-CAL-AAA-00-00018. Working volume is that exposed to Absorption Tower and Stripper (minus Fresh Amine Tank) = 6,113 Tonnes

Unit	NaOH Per Train	Pressure bara	Temp ºC	Normal Tonne / yr	Intermittent Tonne / yr	
Power Generation	Demineralisation Package	6.5	15		17	Note 1, 3
Carbon Capture	Thermal Recovery Unit (TRU)	6.5	15		495	Note 2, 3
Carbon Capture	Ion Exchange (IX) Package	6.5	15		1,156	Note 1, 3
Water Treatment	Water Treatment Plant	6.5	15		1,729	Note 2, 3
			Total	-	3,398	

Notes:
1. 4% Caustic Solution
2. 20% Caustic Solution
3. Flow rates are for stored 47% Caustic solution not for dliuted solution supplied to users.

Unit	H_2SO_4 Per Train	Pressure bara	Temp ºC	Normal Tonne / yr	Intermittent Tonne / yr
Water Treatment	Water Treatment Plant				966
Carbon Capture	Acid Wash			313	
			Total	313	966

Unit	METHANOL Per Train	Pressure bara	Temp ºC	Normal Tonne / yr	Intermittent Tonne / yr
Water Treatment	Water Treatment Plant				541

	Total	-	541

Unit	ACETIC ACID Per Train	Pressure bara	Temp ºC	Normal Tonne / yr	Intermittent Tonne / yr
Water Treatment	Water Treatment Plant				735

	Total	-	735

Unit	SODIUM BICARBONATE Per Train	Pressure bara	Temp ºC	Normal Tonne / yr	Intermittent Tonne / yr
Water Treatment	Water Treatment Plant				2,369

	Total	-	2,369

Unit	PHOSPHORIC ACID Per Train	Pressure bara	Temp ºC	Normal Tonne / yr	Intermittent Tonne / yr
Water Treatment	Water Treatment Plant				803

	Total	-	803

Unit	ANTI-SCALANT Per Train	Pressure bara	Temp ºC	Normal Tonne / yr	Intermittent Tonne / yr
Water Treatment	Water Treatment Plant				60

	Total	-	60

Unit	TRACER Per Train	Pressure bara	Temp ºC	Normal Tonne / yr	Intermittent Tonne / yr
Compression	Tracer Dosing Package				0.5

	Total	-	0.5

Unit	OXYGEN SCAVENGER Per Train	Pressure bara	Temp ºC	Normal m3 / yr	Intermittent m3 / yr	
Power Generation	Boiler Feedwater			2	-	Note a

	Total	2	-

Unit	PHOSPHATE Per Train	Pressure bara	Temp ºC	Normal m3 / yr	Intermittent m3 / yr	
Power Generation	Boiler Feedwater			9	-	Note a

	Total	9	-

Unit	ALKALI Per Train	Pressure bara	Temp ºC	Normal m3 / yr	Intermittent m3 / yr	
Power Generation	Boiler Feedwater			131	-	Note a

	Total	131	-

Unit	CORROSION INHIBITOR Per Train	Pressure bara	Temp ºC	Normal m3 / yr	Intermittent m3 / yr	
Power Generation	Boiler Feedwater			66	-	Note a

	Total	66	-

Unit	ANTIFREEZE Per Train	Pressure bara	Temp ºC	Normal m3 / yr	Intermittent m3 / yr
Power Generation	Closed Circuit Cooling			-	-

	Total	-	-

Notes:
a. Based on slightly larger Rankine Cycle

Unit	User (SEA WATER) Per Platform	Pressure	Temp In	Temp Out	Normal	Rated	Start Up	
		bara	ºC	ºC	m3/hr	m3/hr	m3/hr	
Storage	Well Washing (7 Days)					42		Note 1
				Total	-	42	-	

Unit	User (NITROGEN) Per Platform	Pressure	Temp In	Temp Out	Normal	Rated	Start Up	
		bara	ºC	ºC	kg/hr	kg/hr	kg/hr	
Storage	Wells						93	Note 2
				Total	-	-	-	

Unit	User (DIESEL) Per Platform	Pressure	Temp In	Temp Out	Normal	Rated	Start Up	
		bara	ºC	ºC	ltr/hr	ltr/hr	ltr/hr	
Storage	Diesel Gensets				41	12	41	Note 3
				Total	-	-	-	

NOTES:
1. Water Wash Injection Rate = 41.7 m3/hr
2. Nitrogen Used for Repressurising a Well. 16 cylinder nitrogen quad (186 kg) enough for 2 wells
   Assume consumption is also per month (1 well repressurised per month)
3. Assume 1 genset operating continuously and 2 gensets in operation whilst platform is manned for maintenance work.
4. Sources of information:
   White Rose: K25 - Full Chain Externally Supplied Utility Summary

Attachment 4 – O&M Subcontracts

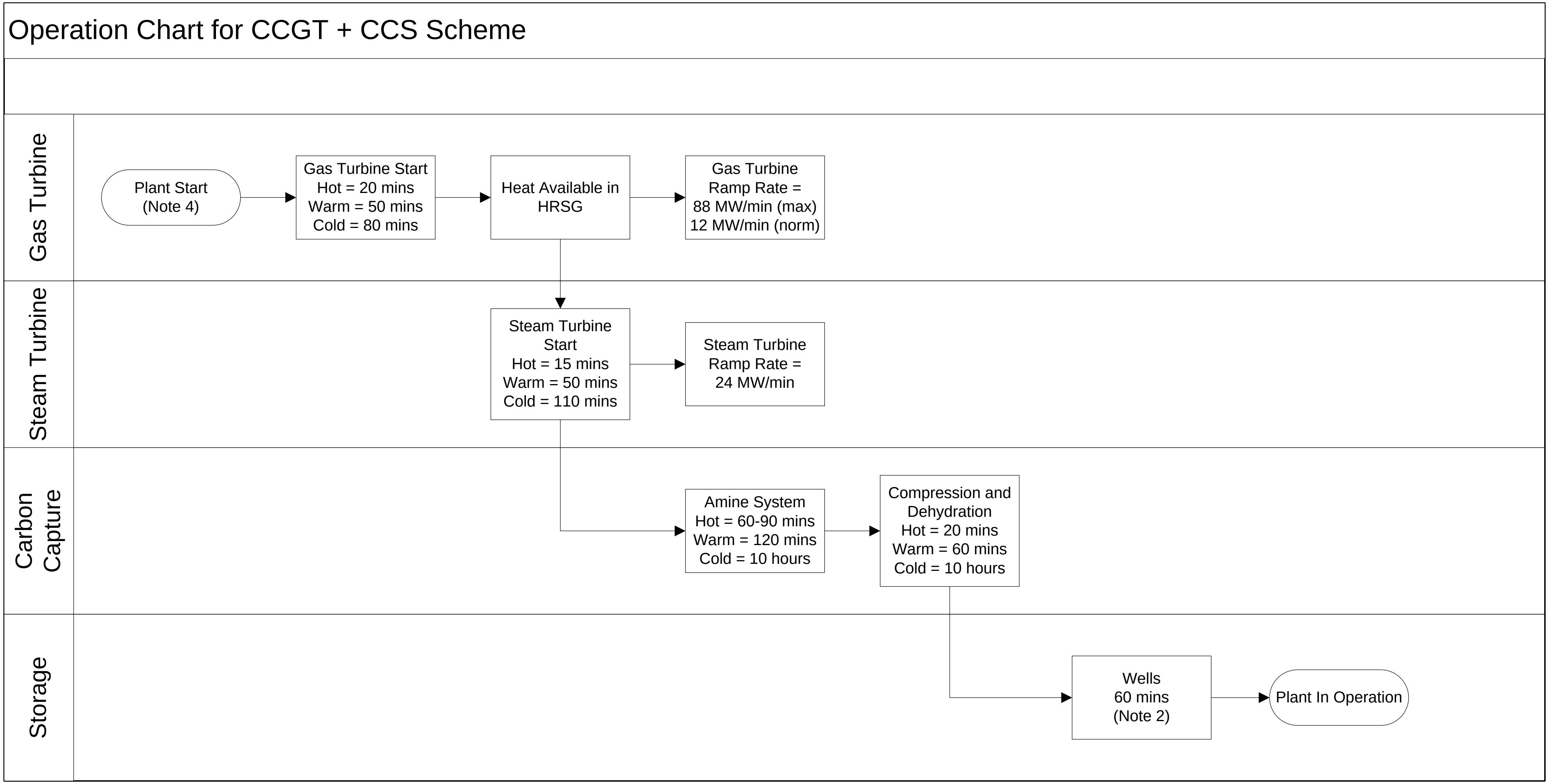
O&M SUBCONTRACTS

Subcontract	Scope	Frequency	Duration
SERVI CES			
Secuirty		Continuous	Continuous
Cleaning		Evening - 5 days per week	Continuous
O&M Contractor (note 4)	Non-Routine Maintenance Modifications	Annually	10 days
	Shutdowns and Turnarounds	6 years	57 days
IT	IT Service Desk, Maintain, and Support. Supply of 9-5 IT Technician	Weekdays	
Scaffolding	Scaffolding to provide maintenance access where permanent platforms not provided.	Annually	5% of technician and craft hours on site
NDT	Ultrasonic, Radiographic, Dye Pen, Mag Particle	Annually	
3rd Party Inspection & Test	Supply of competent persons for Inspection and Test in order to maintain regulatory compliance (e.g. LOLER, PUWER, PSSR)	Annually	
Logistics	Onshore Logisti cs See below for offshore	Annually	
Side Scan Sonar	Route survey of Subsea Pipelines	5 years	1 week + report
ROV	Subsea Inspection and Maintenance, pipelines, subsea valves, substructures, cables	Annually	1 week + report
Training	Offshore Survival (All Ops and Maint Technical Staff) HSE First Aid Technical Apprentices	Tech Staff: 14 HSE Courses pre-operation + refreshers. 1 x Offshore Survival. Repeat every 4 years	Mix 3 Days
SUPPLY / HIRE			
Walk to Work Vessel	Supply walk to work vessel to take O&M team out to platform. Assume: 1 day preparation 1 day travel 8 days on station 1 day return 1 day unload 2 day contingency	2 Platforms: Every Month 1 Platform: Every other Month	14 Days
Supply Boat	To support Walk to Work Vessel See above	See above	See above
EQUIPMENT OEMs			
Included in the maintenance			
schedule			

NOTES

1. Chemical and material supply is covered elsewhere

Attachment 5 – Start-Up Sequence



NOTES:

1. Information Sources:
   FEED Summary Report for Full CCS Chain, PCCS-00-MM-AA-7180-00001, Shell UK Limited
   Powering the Future with Gas Power Systems, 2017 Offerings, GE
   Chief Technologist experience from previous CCS
2. Wells to be maintained at temperature by reducing settings to minimum flow and using pipeline pack pressure to maintain operation. Shell Peterhead estimated that there was 2 hours of line pack to maintain this operation before shutdown and a complete well re-start sequence was required.
3. Cold Start > 16 hours
   Warm Start 6 – 16 hours
   Hot Start < 6 hours
4. Assume utilities are charged and available (Air, Cooling Water, etc) – newly (re)commissioned plant start-up will be a longer sequence.
5. Water should be circulating through the DCC (Direct Contact Cooler) before admitting CCGT flue gases into CC plant. Steam lines to the reboilers require warming if a cold start (this takes at least a shift) prior to admitting flue gases in the CC plant.
6. Cold start for Compression and Dehydration is a depressurised state. Re-start includes re-pressurisation of the system.
7. It is assumed that the start times listed for the GTG Start are delay times for steam out the HRSG and the STG times are wait times before STG ramping.

Attachment 6 – Operating and Turndown Scenarios

Operating and Turndown Scenarios

Operation Modes

There will be periods when the Thermal Power with CCS Plant does not need to operate. There is an economic decision to be made by the Owner as to how long the plant is held in readiness, and at what level of readiness is appropriate.

The Start-Up times are taken from the start up sequence chart in Attachment 5 of this report.

The following table is an investigation into the different operating and turndown scenarios.

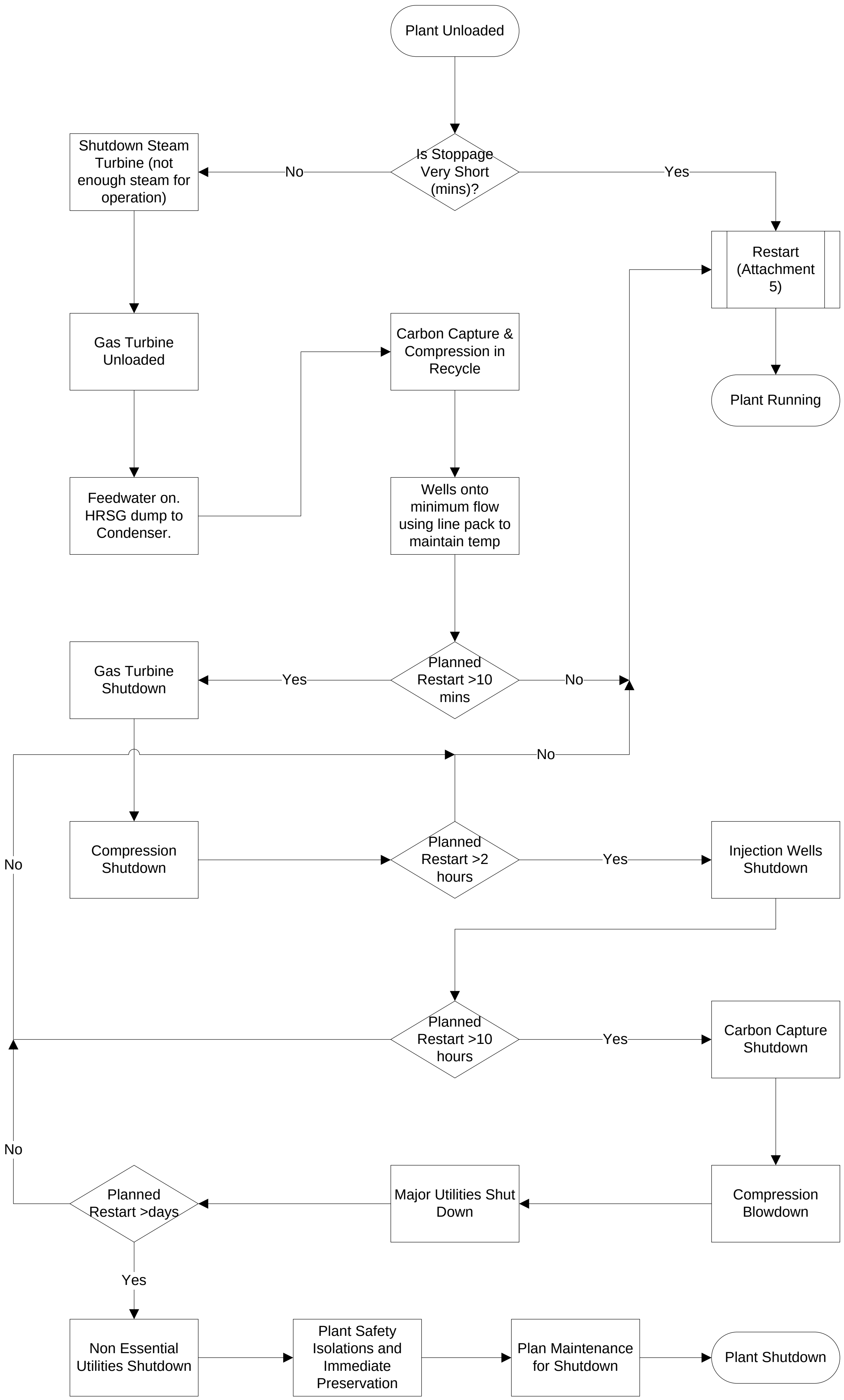
Level	Description	Output (Per Train)	Utilities (Per Train)	Costs (Per Train)	Emissions (Per Train)
Start-Up	Hot	0 MW		Utility Co. + Articles indicate around £10,000 per start per train for CCGT. CCS start cost will depend on whether any other trains in operation – i.e. does injection have to be restarted?	145 minutes CO_2 @ 243 T/hr
	Warm	0 MW			340 minutes CO_2 @ 243 T/hr
	Cold	0 MW			1390 minutes CO_2 @ 243 T/hr
Unabated Operation	Unabated Operation Carbon Capture Off	715 MW	Fuel = 32 Nm^3/sec	Assume spot price higher than CfD otherwise would not operate in this mode (unless Storage was down) CO_2 emission costs	243 T/hr
	Unabated Operation	678 MW	Fuel = 32 Nm^3/sec	37 MW total lost	243 T/hr

Level	Description	Output (Per Train)	Utilities (Per Train)	Costs (Per Train)	Emissions (Per Train)
	Carbon Capture in Recycle		Carbon capture = 5.1 MW (based on 5 trains) 40% of steam to operate reboilers in reflux to keep system warm	power output. Assume spot price higher than CfD otherwise would not operate in this mode (unless Storage was down) CO_2 emission costs	
Normal	CCGT at 100% Load CCS at 100 % Load	622 MW	Fuel = 32 Nm^3/sec	Normal O&M cost model	24 T/hr
Turndown	CCGT at 40% CCS at 40% (Note that although GT is turndown to 40% the heat recovery means that the CCGT output is higher)	304 MW	Fuel = 17 Nm^3/sec	Less dilution of fixed O&M costs against output. Variable costs proportionate to CCGT output.	13 T/hr
Total Recycle	The plant is left operating on no load. Insufficient steam to Steam Turbine which has to be shutdown and steam extraction to carbon capture is lost. Feedwater must be supplied to HRSG to protect tubes. Operating experience is that temperature control in HRSG is difficult (HRSG	0 MW	Fuel = 17 Nm^3/sec	Fixed and variable O&M costs without revenue. ~£70k / hr fuel cost vrs restart cost. Depends on wells, but looks like would only keep unloaded for 10 to 15 minutes.	13 T/hr

Level	Description	Output (Per Train)	Utilities (Per Train)	Costs (Per Train)	Emissions (Per Train)
	highly optimised for 100% load). Steam production bypassed to condenser. Carbon capture cools down as no steam extraction. This is a mode that the operator would not wish to sustain for long.				
CC Recycle & CO_2 Comp pressured	The CCGT unit is shut down. The CCC unit is left on recycle. The utilities costs are lower than total recycle. This mode is suitable for a limited period because it allows carbon capture to be brought back online quickly. However, without steam from the Steam Turbine extraction, the temperature of the amine will drop. It is planned that the Auxiliary boiler would be used to keep the steam run from CCGT to CC units warm. The Compression and Dehydration unit is kept pressurised in order to	0 MW	5.1 MW electrical load 962 Nm^3/hr natural gas for Auxiliary Boiler		Assume electrical load imported power. 428 kg/hr CO_2 (net)

Level	Description	Output (Per Train)	Utilities (Per Train)	Costs (Per Train)	Emissions (Per Train)
	restart quicker. However, without heat the wet side of the compression system will begin to collect condensate as the CO_2 cools.				
Shutdown	The CCGT and CCC units are shutdown and Blowdown. This minimises utility consumption. CCGT + CCS Scheme safety isolation put in place and Immediate Preservation actions put in place (i.e. drain any condensate from wet side CO_2). Opportunity for maintenance intervention during downtime.	0 MW	Essential utilities only	Fixed O&M costs. Additional offshore intervention required with cost.	Minor

Attachment 7 – Shutdown Sequence


Plant Unloaded
Is Stoppage Very Short (mins)?
No
Yes
Shutdown Steam Turbine (not enough steam for operation)
Restart (Attachment 5)
Gas Turbine Unloaded
Carbon Capture & Compression in Recycle
Plant Running
Feedwater on. HRSG dump to Condenser.
Wells onto minimum flow using line pack to maintain temp
Gas Turbine Shutdown
Yes
Planned Restart >10 mins
No
No
Compression Shutdown
Planned Restart >2 hours
Yes
Injection Wells Shutdown
No
Planned Restart >10 hours
Yes
Carbon Capture Shutdown
No
Planned Restart >days
Major Utilities Shut Down
Compression Blowdown
Yes
Non Essential Utilities Shutdown
Plant Safety Isolations and Immediate Preservation
Plan Maintenance for Shutdown
Plant Shutdown

Attachment 8 – OPEX Model

OPEX Summary

Project Information	
Project Number	181869
Project Name	Thermal Power with CCS - Generic Business Case
Selected Location	Generic - UK

Opex Model Summary		
Staff Level	105.5	Ref: Operating Staff Worksheet
Trains	1	
Output per Train	621	Source: 181869-0001-T-EM-REP-AAA-00-00004
Currency	GBP	All costs converted to GBP (calcs shown where vendor data USD/other)
Exchange Rate (as needed)	USD/GBP	1.27653 xe.com
	EUR/GBP	1.13141 xe.com

Trains	Per Train	1	
Plant Output - Gross	732	732	
Gross minus parasitic	715		
Steam Abated	690		
Parasitic Electrical Lo	69		
Net Abated	621	621	Additional availability reduction in Yr 1-2
Availability year 1		85%	73.33%
Availbility year 2		90%	84.33%
Availability Year 3		100%	86.91%
Operating Life		25.00	Years
Operating Conditions		24.00	hrs/day
Days/yr		365.00	
CAPEX (P50)		1,761,659,942	

CAPEX - Teesside P50				
1	2	3	4	5
1,761,659,942	2,728,050,770	3,735,069,472	4,983,587,617	5,934,550,599

Strike Price	90	£/Mw
Natural Gas Input		p/Therm
if blank, default to 5-year average)		
Avg Opex	265,795,650	

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Revenue / Yr	359,015,004	412,887,375	501,570,792	464,294,997	465,518,988	410,405,859	467,966,970	469,190,961	425,170,879	469,925,356	470,414,952	414,077,832	470,414,952	469,925,356	431,877,679

Operating Expenses	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
Availability	88.33%	94.33%	86.91%	94.83%	95.08%	83.83%	95.58%	95.83%	86.84%	95.98%	96.08%	84.58%	96.08%	95.98%	88.21%
Variable Expenses															
Utilities	209,615	239,042	246,313	268,649	269,354	239,212	270,764	271,469	246,116	271,892	273,774	239,727	272,174	271,892	249,979
Fuel Gas	133,318,897	153,324,203	158,012,655	172,414,234	172,868,758	152,402,701	173,777,807	174,232,332	157,885,637	174,505,047	174,686,857	153,766,275	174,686,857	174,505,047	160,376,182
Consumables	6,753,252	7,689,941	7,909,464	7,909,464	7,909,464	7,909,464	7,909,464	7,909,464	7,909,464	7,909,464	7,909,464	7,909,464	7,909,464	7,909,464	7,909,464
Disposals	185,176	185,176	185,176	185,176	185,176	185,176	185,176	185,176	185,176	185,176	185,176	185,176	185,176	185,176	185,176
Subcontracts - Variable	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Carbon Tax	3,642,447	3,999,861	4,083,625	4,340,923	4,349,043	3,983,397	4,365,284	4,373,405	4,081,355	4,378,277	4,381,525	4,007,759	4,381,525	4,378,277	4,125,851
Cost for Cold Starts	1,487,431	1,487,431	1,487,431	1,487,431	1,487,431	1,487,431	1,487,431	1,487,431	1,487,431	1,487,431	1,487,431	1,487,431	1,487,431	1,487,431	1,487,431
Costs for Warm Starts	1,189,945	1,189,945	1,189,945	1,189,945	1,189,945	1,189,945	1,189,945	1,189,945	1,189,945	1,189,945	1,189,945	1,189,945	1,189,945	1,189,945	1,189,945
Costs for Hot Starts	495,810	495,810	495,810	495,810	495,810	495,810	495,810	495,810	495,810	495,810	495,810	495,810	495,810	495,810	495,810
Total Variable Expenses	*147,282,572*	*168,611,408*	*173,610,418*	*188,291,631*	*188,754,981*	*167,893,137*	*189,681,681*	*190,145,031*	*173,480,934*	*190,423,041*	*190,609,981*	*169,281,586*	*190,608,381*	*190,423,041*	*176,019,838*
Fixed Expenses															
Labour	10,377,942	10,377,942	10,377,942	10,377,942	10,377,942	10,377,942	10,377,942	10,377,942	10,377,942	10,377,942	10,377,942	10,377,942	10,377,942	10,377,942	10,377,942
Maintenance	14,813,850	6,178,033	10,393,121	6,178,033	41,016,958	21,698,412	5,653,791	6,178,033	10,393,121	41,883,200	5,653,791	22,471,945	5,653,791	6,178,033	45,756,289
Regulatory Expenses	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000
Subcontracts - Fixed	2,689,651	2,689,651	2,689,651	2,689,651	2,917,651	14,029,651	2,689,651	2,689,651	2,689,651	2,917,651	2,689,651	14,029,651	2,689,651	2,689,651	2,917,651
Administrative and Other Expense	62,245,531	51,545,805	51,599,015	51,576,649	51,577,383	51,544,316	51,578,852	51,579,587	51,553,175	51,580,027	51,580,321	51,546,519	51,580,321	51,580,027	51,557,199
Total Fixed Expenses	*90,156,973*	*70,821,429*	*75,089,728*	*70,852,274*	*105,919,934*	*97,680,320*	*70,330,236*	*70,855,211*	*75,043,888*	*106,788,819*	*70,331,704*	*98,456,056*	*70,331,704*	*70,855,652*	*110,639,080*
Total OPEX	**237,439,545**	**239,432,837**	**248,700,146**	**259,143,905**	**294,674,915**	**265,573,456**	**260,011,916**	**261,000,242**	**248,524,822**	**297,211,860**	**260,941,685**	**267,737,643**	**260,940,085**	**261,278,693**	**286,658,917**

MWhr/yr	4,805,050	5,131,634	4,727,921	5,158,833	5,172,433	4,560,065	5,199,633	5,213,233	4,724,121	5,221,393	5,226,833	4,600,865	5,226,833	5,221,393	4,798,641
Planned Outage Factors	7.67%	1.92%	9.59%	1.92%	1.92%	13.42%	1.92%	1.92%	10.96%	1.92%	1.92%	13.42%	1.92%	1.92%	9.59%
Forced Outage Factors	4.0%	3.8%	3.5%	3.3%	3.0%	2.8%	2.5%	2.3%	2.2%	2.1%	2.0%	2.0%	2.0%	2.1%	2.2%
Total Outage Factor	11.67%	5.67%	13.09%	5.17%	4.92%	16.17%	4.42%	4.17%	13.16%	4.02%	3.92%	15.42%	3.92%	4.02%	11.79%
Days of outage	42.6	20.7	47.8	18.9	18.0	59.0	16.1	15.2	48.0	14.7	14.3	56.3	14.3	14.7	43.0
Projected Number of Cold Starts	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Projected Number of Warm Starts	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Projected Number of Hot starts	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12

Number of starts have come from TNT-00014 - Plant Operating Scenarios
Number of starts noes not correlate to outage time - additional fatigue cost of an outage is calculated in 'Cost of a Restart'
Forced outage factor increases over time as wear and tear on plant and equipment increases
Source for forced outage factor:
http://pennwell.sds06.websds.net/2015/bangkok/apw/papers/T4S7O2-paper.pdf
Planned outage factor is calculated based on the required number of days shutdown required for maintenance work per year/365days

Year 16	Year 17	Year 18	Year 19	Year 20	Year 21	Year 22	Year 23	Year 24	Year 25
16	17	18	19	20	21	22	23	24	25
469,190,961	468,701,365	411,874,648	467,966,970	467,722,172	429,919,294	466,742,979	465,029,392	407,223,482	461,112,620

Year 16	Year 17	Year 18	Year 19	Year 20	Year 21	Year 22	Year 23	Year 24	Year 25
95.83%	95.73%	84.13%	95.58%	95.53%	87.81%	95.33%	94.98%	83.18%	94.18%
273,069	271,187	238,458	270,764	270,623	250,451	270,059	269,072	235,780	266,816
174,232,332	174,050,522	152,948,131	173,777,807	173,686,903	159,648,943	173,323,283	172,686,949	151,220,937	171,232,470
7,909,464	7,909,464	7,909,464	7,909,464	7,909,464	7,909,464	7,909,464	7,909,464	7,909,464	7,909,464
185,176	185,176	185,176	185,176	185,176	185,176	185,176	185,176	185,176	185,176
-	-	-	-	-	-	-	-	-	-
4,373,405	4,370,157	3,993,142	4,365,284	4,363,660	4,112,859	4,357,164	4,345,795	3,962,284	4,319,809
1,487,431	1,487,431	1,487,431	1,487,431	1,487,431	1,487,431	1,487,431	1,487,431	1,487,431	1,487,431
1,189,945	1,189,945	1,189,945	1,189,945	1,189,945	1,189,945	1,189,945	1,189,945	1,189,945	1,189,945
495,810	495,810	495,810	495,810	495,810	495,810	495,810	495,810	495,810	495,810
190,146,631	*189,959,691*	*168,447,556*	*189,681,681*	*189,589,011*	*175,280,078*	*189,218,331*	*188,569,641*	*166,686,826*	*187,086,921*
10,377,942	10,377,942	10,377,942	10,377,942	10,377,942	10,377,942	10,377,942	10,377,942	10,377,942	10,377,942
21,858,437	5,653,791	21,698,412	5,653,791	41,883,200	10,393,121	6,178,033	5,653,791	22,471,945	49,707,750
30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000
2,689,651	2,689,651	14,029,651	2,689,651	2,917,651	2,689,651	2,689,651	2,689,651	14,029,651	2,917,651
51,579,587	51,579,293	51,545,197	51,578,852	51,578,705	51,556,024	51,578,118	51,577,090	51,542,406	51,574,740
86,535,615	*70,330,676*	*97,681,201*	*70,330,236*	*106,787,497*	*75,046,737*	*70,853,743*	*70,328,473*	*98,451,944*	*114,608,082*
276,682,246	**260,290,367**	**266,128,757**	**260,011,916**	**296,376,508**	**250,326,815**	**260,072,073**	**258,898,114**	**265,138,770**	**301,695,003**

5,213,233	5,207,793	4,576,385	5,199,633	5,196,913	4,776,881	5,186,033	5,166,993	4,524,705	5,123,474
1.92%	1.92%	13.42%	1.92%	1.92%	9.59%	1.92%	1.92%	13.42%	1.92%
2.3%	2.4%	2.5%	2.5%	2.6%	2.6%	2.8%	3.1%	3.4%	3.9%
4.17%	4.27%	15.87%	4.42%	4.47%	12.19%	4.67%	5.02%	16.82%	5.82%
15.2	15.6	57.9	16.1	16.3	44.5	17.0	18.3	61.4	21.2
3	3	3	3	3	3	3	3	3	3
4	4	4	4	4	4	4	4	4	4
5	5	5	5	5	5	5	5	5	5
12	12	12	12	12	12	12	12	12	12

OPEX Summary by Area

Project Information		
Project Number	181869	
Project Name	Thermal Power with CCS - Generic Business Case	
Selected Location	Generic - UK	

Opex Model Summary			
Staff Level	105.5	Ref: Operating Staff Worksheet	
Trains	1		
Output per Train	622	Source: 181869-0001-T-EM-REP-AAA-00-00004	
Currency	GBP	All costs converted to GBP (calcs shown where vendor data USD/other)	
Exchange Rate (as needed)	USD/GBP	1.27653	xe.com
	EUR/GBP	1.13141	xe.com

Operating Expenses	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
CCGT										
Variable Expenses										
Utilities	104,807	119,521	123,157	134,324	134,677	119,606	135,382	135,734	123,058	135,946
Fuel Gas	133,318,897	153,324,203	158,012,655	172,414,234	172,868,758	152,402,701	173,777,807	174,232,332	157,885,637	174,505,047
Consumables	1,891,237	2,174,938	2,241,426	2,241,426	2,241,426	2,241,426	2,241,426	2,241,426	2,241,426	2,241,426
Disposals	45,794	45,794	45,794	45,794	45,794	45,794	45,794	45,794	45,794	45,794
Subcontracts - Variable	-	-	-	-	-	-	-	-	-	-
Carbon Tax	3,642,447	3,999,861	4,083,625	4,340,923	4,349,043	3,983,397	4,365,284	4,373,405	4,081,355	4,378,277
Cost for Cold Starts	1,487,431	1,487,431	1,487,431	1,487,431	1,487,431	1,487,431	1,487,431	1,487,431	1,487,431	1,487,431
Costs for Warm Starts	1,189,945	1,189,945	1,189,945	1,189,945	1,189,945	1,189,945	1,189,945	1,189,945	1,189,945	1,189,945
Costs for Hot Starts	495,810	495,810	495,810	495,810	495,810	495,810	495,810	495,810	495,810	495,810
Total Variable Expenses	*142,176,368*	*162,837,503*	*167,679,843*	*182,349,888*	*182,812,885*	*161,966,111*	*183,738,880*	*184,201,878*	*167,550,457*	*184,479,676*
Fixed Expenses										
Labour	4,408,619	4,408,619	4,408,619	4,408,619	4,408,619	4,408,619	4,408,619	4,408,619	4,408,619	4,408,619
Maintenance	3,178,611	3,575,585	7,574,059	3,575,585	3,051,344	18,631,611	3,051,344	3,575,585	7,574,059	3,575,585
Regulatory Expenses	7,500	7,500	7,500	7,500	7,500	7,500	7,500	7,500	7,500	7,500
Subcontracts - Fixed	1,010,449	1,010,449	1,010,449	1,010,449	1,010,449	6,680,449	1,010,449	1,010,449	1,010,449	1,010,449
Administrative and Other Expenses	21,400,774	21,897,000	21,919,604	21,910,103	21,910,415	21,896,368	21,911,039	21,911,351	21,900,131	21,911,538
Total Fixed Expenses	*30,005,952*	*30,899,153*	*34,920,231*	*30,912,256*	*30,388,327*	*51,624,546*	*30,388,951*	*30,913,504*	*34,900,758*	*30,913,691*
Subtotal CCGT	**172,182,320**	**193,736,656**	**202,600,074**	**213,262,144**	**213,201,212**	**213,590,658**	**214,127,831**	**215,115,382**	**202,451,215**	**215,393,367**
CCC										
Variable Expenses										
Utilities	104,807	119,521	123,157	134,324	134,677	119,606	135,382	135,734	123,058	135,946
Consumables	4,351,626	5,004,614	5,157,648	5,157,648	5,157,648	5,157,648	5,157,648	5,157,648	5,157,648	5,157,648
Disposals	139,382	139,382	139,382	139,382	139,382	139,382	139,382	139,382	139,382	139,382
Subcontracts - Variable	-	-	-	-	-	-	-	-	-	-
Cost for Cold Starts										
Costs for Warm Starts										
Costs for Hot Starts										
Total Variable Expenses	*4,595,815*	*5,263,516*	*5,420,186*	*5,431,354*	*5,431,706*	*5,416,636*	*5,432,411*	*5,432,764*	*5,420,088*	*5,432,975*
Fixed Expenses										
Labour	4,408,619	4,408,619	4,408,619	4,408,619	4,408,619	4,408,619	4,408,619	4,408,619	4,408,619	4,408,619
Maintenance	1,097,617	1,097,617	1,314,232	1,097,617	1,097,617	1,561,971	1,097,617	1,097,617	1,314,232	1,097,617
Regulatory Expenses	7,500	7,500	7,500	7,500	7,500	7,500	7,500	7,500	7,500	7,500
Subcontracts - Fixed	1,010,449	1,010,449	1,010,449	1,010,449	1,010,449	6,680,449	1,010,449	1,010,449	1,010,449	1,010,449
Administrative and Other Expenses	32,132,824	21,897,000	21,919,604	21,910,103	21,910,415	21,896,368	21,911,039	21,911,351	21,900,131	21,911,538
Total Fixed Expenses	*38,657,008*	*28,421,185*	*28,660,404*	*28,434,288*	*28,434,600*	*34,554,906*	*28,435,224*	*28,435,536*	*28,640,931*	*28,435,723*
Subtotal CCC	**43,252,823**	**33,684,701**	**34,080,590**	**33,865,642**	**33,866,306**	**39,971,542**	**33,867,635**	**33,868,300**	**34,061,018**	**33,868,698**
Pipelines										
Variable Expenses										

OPEX Summary by Area

Project Information	
Project Number	181869
Project Name	Thermal Power with CCS - Generic Business Case
Selected Location	Generic - UK

Opex Model Summary			
Staff Level	105.5	Ref: Operating Staff Worksheet	
Trains	1		
Output per Train	622	Source: 181869-0001-T-EM-REP-AAA-00-00004	
Currency	GBP	All costs converted to GBP (calcs shown where vendor data USD/other)	
Exchange Rate (as needed)	USD/GBP	1.27653	xe.com
	EUR/GBP	1.13141	xe.com

Operating Expenses	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Utilities	-	-	-	-	-	-	-	-	-	-
Consumables	-	-	-	-	-	-	-	-	-	-
Disposals										
Subcontracts - Variable										
Cost for Cold Starts										
Costs for Warm Starts										
Costs for Hot Starts										
Total Variable Expenses	-	-	-	-	-	-	-	-	-	-
Fixed Expenses										
Labour	414,557	414,557	414,557	414,557	414,557	414,557	414,557	414,557	414,557	414,557
Maintenance	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000
Regulatory Expenses	7,500	7,500	7,500	7,500	7,500	7,500	7,500	7,500	7,500	7,500
Subcontracts - Fixed	-	-	-	-	228,000	-	-	-	-	228,000
Administrative and Other Expenses	2,012,385	2,059,047	2,061,173	2,060,279	2,060,309	2,058,988	2,060,367	2,060,397	2,059,342	2,060,414
Total Fixed Expenses	*3,844,442*	*3,891,104*	*3,893,230*	*3,892,336*	*4,120,366*	*3,891,045*	*3,892,424*	*3,892,454*	*3,891,399*	*4,120,471*
Subtotal Pipelines	**3,844,442**	**3,891,104**	**3,893,230**	**3,892,336**	**4,120,366**	**3,891,045**	**3,892,424**	**3,892,454**	**3,891,399**	**4,120,471**
Offshore										
Variable Expenses										
Utilities										
Consumables	510,389	510,389	510,389	510,389	510,389	510,389	510,389	510,389	510,389	510,389
Disposals	-	-	-	-	-	-	-	-	-	-
Subcontracts - Variable										
Cost for Cold Starts										
Costs for Warm Starts										
Costs for Hot Starts										
Total Variable Expenses	*510,389*	*510,389*	*510,389*	*510,389*	*510,389*	*510,389*	*510,389*	*510,389*	*510,389*	*510,389*
Fixed Expenses										
Labour	1,146,148	1,146,148	1,146,148	1,146,148	1,146,148	1,146,148	1,146,148	1,146,148	1,146,148	1,146,148
Maintenance	9,127,622	94,831	94,831	94,831	35,457,998	94,831	94,831	94,831	94,831	35,799,998
Regulatory Expenses	7,500	7,500	7,500	7,500	7,500	7,500	7,500	7,500	7,500	7,500
Subcontracts - Fixed	668,752	668,752	668,752	668,752	668,752	668,752	668,752	668,752	668,752	668,752
Administrative and Other Expenses	6,699,548	5,692,757	5,698,633	5,696,163	5,696,244	5,692,592	5,696,407	5,696,488	5,693,571	5,696,536
Total Fixed Expenses	*17,649,570*	*7,609,987*	*7,615,863*	*7,613,393*	*42,976,642*	*7,609,822*	*7,613,637*	*7,613,718*	*7,610,801*	*43,318,934*
Subtotal Offshore	**18,159,960**	**8,120,376**	**8,126,253**	**8,123,783**	**43,487,031**	**8,120,212**	**8,124,026**	**8,124,107**	**8,121,190**	**43,829,323**
Total	**237,439,545**	**239,432,837**	**248,700,146**	**259,143,905**	**294,674,915**	**265,573,456**	**260,011,916**	**261,000,242**	**248,524,822**	**297,211,860**
	-	-	-	-	-	-	-	-	-	-

OPEX Summary by Area

Project Number
Project Name
Selected Location

Opex Model S
Staff Level
Trains
Output per Train
Currency
Exchange Rate (as needed)

Operating Expenses	Year 11	Year 12	Year 13	Year 14	Year 15	Year 16	Year 17	Year 18	Year 19
CCGT									
Variable Expenses									
Utilities	136,887	119,864	136,087	135,946	124,989	136,534	135,593	119,229	135,382
Fuel Gas	174,686,857	153,766,275	174,686,857	174,505,047	160,376,182	174,232,332	174,050,522	152,948,131	173,777,807
Consumables	2,241,426	2,241,426	2,241,426	2,241,426	2,241,426	2,241,426	2,241,426	2,241,426	2,241,426
Disposals	45,794	45,794	45,794	45,794	45,794	45,794	45,794	45,794	45,794
Subcontracts - Variable	-	-	-	-	-	-	-	-	-
Carbon Tax	4,381,525	4,007,759	4,381,525	4,378,277	4,125,851	4,373,405	4,370,157	3,993,142	4,365,284
Cost for Cold Starts	1,487,431	1,487,431	1,487,431	1,487,431	1,487,431	1,487,431	1,487,431	1,487,431	1,487,431
Costs for Warm Starts	1,189,945	1,189,945	1,189,945	1,189,945	1,189,945	1,189,945	1,189,945	1,189,945	1,189,945
Costs for Hot Starts	495,810	495,810	495,810	495,810	495,810	495,810	495,810	495,810	495,810
Total Variable Expenses	*184,665,675*	*163,354,304*	*184,664,875*	*184,479,676*	*170,087,430*	*184,202,678*	*184,016,679*	*162,520,908*	*183,738,880*
Fixed Expenses									
Labour	4,408,619	4,408,619	4,408,619	4,408,619	4,408,619	4,408,619	4,408,619	4,408,619	4,408,619
Maintenance	3,051,344	19,405,144	3,051,344	3,575,585	7,574,059	3,575,585	3,051,344	18,631,611	3,051,344
Regulatory Expenses	7,500	7,500	7,500	7,500	7,500	7,500	7,500	7,500	7,500
Subcontracts - Fixed	1,010,449	6,680,449	1,010,449	1,010,449	1,010,449	1,010,449	1,010,449	6,680,449	1,010,449
Administrative and Other Expenses	21,911,663	21,897,304	21,911,663	21,911,538	21,901,841	21,911,351	21,911,226	21,896,742	21,911,039
Total Fixed Expenses	*30,389,574*	*52,399,016*	*30,389,574*	*30,913,691*	*34,902,467*	*30,913,504*	*30,389,138*	*51,624,921*	*30,388,951*
Subtotal CCGT	**215,055,250**	**215,753,320**	**215,054,450**	**215,393,367**	**204,989,897**	**215,116,182**	**214,405,816**	**214,145,829**	**214,127,831**
CCC									
Variable Expenses									
Utilities	136,887	119,864	136,087	135,946	124,989	136,534	135,593	119,229	135,382
Consumables	5,157,648	5,157,648	5,157,648	5,157,648	5,157,648	5,157,648	5,157,648	5,157,648	5,157,648
Disposals	139,382	139,382	139,382	139,382	139,382	139,382	139,382	139,382	139,382
Subcontracts - Variable	-	-	-	-	-	-	-	-	-
Cost for Cold Starts									
Costs for Warm Starts									
Costs for Hot Starts									
Total Variable Expenses	*5,433,916*	*5,416,893*	*5,433,116*	*5,432,975*	*5,422,019*	*5,433,564*	*5,432,623*	*5,416,259*	*5,432,411*
Fixed Expenses									
Labour	4,408,619	4,408,619	4,408,619	4,408,619	4,408,619	4,408,619	4,408,619	4,408,619	4,408,619
Maintenance	1,097,617	1,561,971	1,097,617	1,097,617	1,314,232	1,097,617	1,097,617	1,561,971	1,097,617
Regulatory Expenses	7,500	7,500	7,500	7,500	7,500	7,500	7,500	7,500	7,500
Subcontracts - Fixed	1,010,449	6,680,449	1,010,449	1,010,449	1,010,449	1,010,449	1,010,449	6,680,449	1,010,449
Administrative and Other Expenses	21,911,663	21,897,304	21,911,663	21,911,538	21,901,841	21,911,351	21,911,226	21,896,742	21,911,039
Total Fixed Expenses	*28,435,848*	*34,555,842*	*28,435,848*	*28,435,723*	*28,642,640*	*28,435,536*	*28,435,411*	*34,555,281*	*28,435,224*
Subtotal CCC	**33,869,764**	**39,972,735**	**33,868,964**	**33,868,698**	**34,064,659**	**33,869,100**	**33,868,034**	**39,971,539**	**33,867,635**
Pipelines									
Variable Expenses									

OPEX Summary by Area

Project Number
Project Name
Selected Location

Opex Model S
Staff Level
Trains
Output per Train
Currency
Exchange Rate (as needed)

Operating Expenses	Year 11	Year 12	Year 13	Year 14	Year 15	Year 16	Year 17	Year 18	Year 19
Utilities	-	-	-	-	-	-	-	-	-
Consumables	-	-	-	-	-	-	-	-	-
Disposals									
Subcontracts - Variable									
Cost for Cold Starts									
Costs for Warm Starts									
Costs for Hot Starts									
Total Variable Expenses	-	-	-	-	-	-	-	-	-
Fixed Expenses									
Labour	414,557	414,557	414,557	414,557	414,557	414,557	414,557	414,557	414,557
Maintenance	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000
Regulatory Expenses	7,500	7,500	7,500	7,500	7,500	7,500	7,500	7,500	7,500
Subcontracts - Fixed	-	-	-	-	228,000	-	-	-	-
Administrative and Other Expenses	2,060,426	2,059,076	2,060,426	2,060,414	2,059,502	2,060,397	2,060,385	2,059,023	2,060,367
Total Fixed Expenses	*3,892,483*	*3,891,133*	*3,892,483*	*3,892,471*	*4,119,559*	*3,892,454*	*3,892,442*	*3,891,080*	*3,892,424*
Subtotal Pipelines	**3,892,483**	**3,891,133**	**3,892,483**	**3,892,471**	**4,119,559**	**3,892,454**	**3,892,442**	**3,891,080**	**3,892,424**
Offshore									
Variable Expenses									
Utilities									
Consumables	510,389	510,389	510,389	510,389	510,389	510,389	510,389	510,389	510,389
Disposals	-	-	-	-	-	-	-	-	-
Subcontracts - Variable									
Cost for Cold Starts									
Costs for Warm Starts									
Costs for Hot Starts									
Total Variable Expenses	*510,389*	*510,389*	*510,389*	*510,389*	*510,389*	*510,389*	*510,389*	*510,389*	*510,389*
Fixed Expenses									
Labour	1,146,148	1,146,148	1,146,148	1,146,148	1,146,148	1,146,148	1,146,148	1,146,148	1,146,148
Maintenance	94,831	94,831	94,831	94,831	35,457,998	15,775,235	94,831	94,831	94,831
Regulatory Expenses	7,500	7,500	7,500	7,500	7,500	7,500	7,500	7,500	7,500
Subcontracts - Fixed	668,752	668,752	668,752	668,752	668,752	668,752	668,752	668,752	668,752
Administrative and Other Expenses	5,696,569	5,692,836	5,696,569	5,696,536	5,694,015	5,696,488	5,696,455	5,692,690	5,696,407
Total Fixed Expenses	*7,613,799*	*7,610,066*	*7,613,799*	*7,613,766*	*42,974,413*	*23,294,122*	*7,613,685*	*7,609,920*	*7,613,637*
Subtotal Offshore	**8,124,188**	**8,120,455**	**8,124,188**	**8,124,156**	**43,484,802**	**23,804,511**	**8,124,075**	**8,120,309**	**8,124,026**
Total	**260,941,685**	**267,737,643**	**260,940,085**	**261,278,693**	**286,658,917**	**276,682,246**	**260,290,367**	**266,128,757**	**260,011,916**
	-	-	-	-	-	-	-	-	-

OPEX Summary by Area

Project Number
Project Name
Selected Location

Opex Model S
Staff Level
Trains
Output per Train
Currency
Exchange Rate (as needed)

Operating Expenses	Year 20	Year 21	Year 22	Year 23	Year 24	Year 25
CCGT						
Variable Expenses						
Utilities	135,311	125,225	135,029	134,536	117,890	133,408
Fuel Gas	173,686,903	159,648,943	173,323,283	172,686,949	151,220,937	171,232,470
Consumables	2,241,426	2,241,426	2,241,426	2,241,426	2,241,426	2,241,426
Disposals	45,794	45,794	45,794	45,794	45,794	45,794
Subcontracts - Variable	-	-	-	-	-	-
Carbon Tax	4,363,660	4,112,859	4,357,164	4,345,795	3,962,284	4,319,809
Cost for Cold Starts	1,487,431	1,487,431	1,487,431	1,487,431	1,487,431	1,487,431
Costs for Warm Starts	1,189,945	1,189,945	1,189,945	1,189,945	1,189,945	1,189,945
Costs for Hot Starts	495,810	495,810	495,810	495,810	495,810	495,810
Total Variable Expenses	*183,646,281*	*169,347,434*	*183,275,883*	*182,627,686*	*160,761,518*	*181,146,094*
Fixed Expenses						
Labour	4,408,619	4,408,619	4,408,619	4,408,619	4,408,619	4,408,619
Maintenance	3,575,585	7,574,059	3,575,585	3,051,344	19,405,144	3,051,344
Regulatory Expenses	7,500	7,500	7,500	7,500	7,500	7,500
Subcontracts - Fixed	1,010,449	1,010,449	1,010,449	1,010,449	6,680,449	1,010,449
Administrative and Other Expenses	21,910,977	21,901,341	21,910,727	21,910,290	21,895,557	21,909,292
Total Fixed Expenses	*30,913,130*	*34,901,968*	*30,912,880*	*30,388,202*	*52,397,269*	*30,387,203*
Subtotal CCGT	**214,559,410**	**204,249,402**	**214,188,763**	**213,015,888**	**213,158,787**	**211,533,297**
CCC						
Variable Expenses						
Utilities	135,311	125,225	135,029	134,536	117,890	133,408
Consumables	5,157,648	5,157,648	5,157,648	5,157,648	5,157,648	5,157,648
Disposals	139,382	139,382	139,382	139,382	139,382	139,382
Subcontracts - Variable	-	-	-	-	-	-
Cost for Cold Starts						
Costs for Warm Starts						
Costs for Hot Starts						
Total Variable Expenses	*5,432,341*	*5,422,255*	*5,432,059*	*5,431,565*	*5,414,919*	*5,430,438*
Fixed Expenses						
Labour	4,408,619	4,408,619	4,408,619	4,408,619	4,408,619	4,408,619
Maintenance	1,097,617	1,314,232	1,097,617	1,097,617	1,561,971	1,097,617
Regulatory Expenses	7,500	7,500	7,500	7,500	7,500	7,500
Subcontracts - Fixed	1,010,449	1,010,449	1,010,449	1,010,449	6,680,449	1,010,449
Administrative and Other Expenses	21,910,977	21,901,341	21,910,727	21,910,290	21,895,557	21,909,292
Total Fixed Expenses	*28,435,162*	*28,642,141*	*28,434,912*	*28,434,475*	*34,554,095*	*28,433,477*
Subtotal CCC	**33,867,502**	**34,064,396**	**33,866,971**	**33,866,041**	**39,969,014**	**33,863,914**
Pipelines						
Variable Expenses						

OPEX Summary by Area

Project Number	
Project Name	
Selected Location	

Opex Model S	
Staff Level	
Trains	
Output per Train	
Currency	
Exchange Rate (as needed)	

Operating Expenses	Year 20	Year 21	Year 22	Year 23	Year 24	Year 25
Utilities	-	-	-	-	-	-
Consumables	-	-	-	-	-	-
Disposals						
Subcontracts - Variable						
Cost for Cold Starts						
Costs for Warm Starts						
Costs for Hot Starts						
Total Variable Expenses	-	-	-	-	-	-
Fixed Expenses						
Labour	414,557	414,557	414,557	414,557	414,557	414,557
Maintenance	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000
Regulatory Expenses	7,500	7,500	7,500	7,500	7,500	7,500
Subcontracts - Fixed	228,000	-	-	-	-	228,000
Administrative and Other Expenses	2,060,361	2,059,455	2,060,338	2,060,297	2,058,911	2,060,203
Total Fixed Expenses	*4,120,418*	*3,891,512*	*3,892,395*	*3,892,354*	*3,890,968*	*4,120,260*
Subtotal Pipelines	**4,120,418**	**3,891,512**	**3,892,395**	**3,892,354**	**3,890,968**	**4,120,260**
Offshore						
Variable Expenses						
Utilities						
Consumables	510,389	510,389	510,389	510,389	510,389	510,389
Disposals	-	-	-	-	-	-
Subcontracts - Variable						
Cost for Cold Starts						
Costs for Warm Starts						
Costs for Hot Starts						
Total Variable Expenses	*510,389*	*510,389*	*510,389*	*510,389*	*510,389*	*510,389*
Fixed Expenses						
Labour	1,146,148	1,146,148	1,146,148	1,146,148	1,146,148	1,146,148
Maintenance	35,799,998	94,831	94,831	94,831	94,831	44,148,790
Regulatory Expenses	7,500	7,500	7,500	7,500	7,500	7,500
Subcontracts - Fixed	668,752	668,752	668,752	668,752	668,752	668,752
Administrative and Other Expenses	5,696,390	5,693,885	5,696,325	5,696,212	5,692,381	5,695,952
Total Fixed Expenses	*43,318,788*	*7,611,116*	*7,613,556*	*7,613,442*	*7,609,612*	*51,667,142*
Subtotal Offshore	**43,829,177**	**8,121,505**	**8,123,945**	**8,123,831**	**8,120,001**	**52,177,531**
Total	**296,376,508**	**250,326,815**	**260,072,073**	**258,898,114**	**265,138,770**	**301,695,003**
	-	-	-	-	-	-

Operating Staff Costs

No of Trains: 1

Role	No	Number - scaled to trains					Rate	Overhead and/or Shift Premium	Total Salary (Specified trains)	Note
Operations	5	4	3	2	1	Schedule				
Operations Director	1	1	1	1	1	5x8	90,000	67,500	157,500	Teesside
Operations Manager	1	1	1	1	1	5x8	75,000	56,250	131,250	prorata
Shift Superintendent	6	6	5	5	5	4x10 shift rotation	48,000	60,000	540,000	Teesside
Plant Engineers	6	6	5	5	5	4x10 shift rotation	42,000	52,500	472,500	Teesside
Operators	24	20	14	11	5	4x10 shift rotation	48,000	60,000	540,000	Teesside
Apprentice Operators	6	5	4	3	3	4x10 shift rotation	30,000	37,500	202,500	SNC data
Chemist	1	1	1	1	1	5x8	27,000	20,250	47,250	glassdoor
Lab Technician	2	2	2	1	1	5x8	28,000	21,000	49,000	Teesside
Waste Treatment Specialist	1	1	1	1	1	5x8	28,500	21,375	49,875	glassdoor
HSSE Officer	1	1	1	1	1	5x8	42,750	32,063	74,813	SNC data
HSSE Engineer	2	2	2	1	1	4x10 shift rotation	34,186	42,733	76,919	SNC data
Process Engineer	1	1	1	1	1	5x8	51,817	38,863	90,680	SNC data
Performance Technician	2	2	2	1	1	5x8	31,457	23,593	55,050	SNC data
Trainer	1	1	1	1	1	5x8	48,000	36,000	84,000	SNC data
Maintenance										
Maintenance Manager	1	1	1	1	1	5x8	75,000	56,250	131,250	SNC data
Mechanical Engineer	2	2	2	1	1	5x8	50,937	38,203	89,140	SNC data
Mechanical Technician	10	8	6	4	2	5x8	33,180	24,885	116,130	SNC data
Mechanical Apprentice	2	2	1	1	0	5x8	25,000	18,750	-	SNC data
Electrical Engineer	2	2	2	1	1	5x8	51,368	38,526	89,894	SNC data
Electrical Technician	10	8	6	4	2	5x8	34,356	25,767	120,246	SNC data
Electrical Apprentice	2	1	1	1	0	5x8	25,000	18,750	-	SNC data
Controls and Instrumentation Engineer	2	2	2	1	1	5x8	55,535	41,651	97,186	SNC data
C&I Technician	6	5	4	3	2	5x8	33,615	25,211	117,653	SNC data
C&I Apprentice	1	1	1	1	0	5x8	25,000	18,750	-	SNC data
Maintenance Superintendent	1	1	1	1	1	5x8	67,000	50,250	117,250	Glassdoor - low end
Maintenance Planner	2	2	2	1	1	5x8	49,700	37,275	86,975	SNC data
Planner Apprentice	1	1	1	1	0	5x8	25,000	18,750	-	SNC data
Mechanical Trades	18	14	11	8	5	5x8	35,360	26,520	309,400	SNC data
Electrical Trades	6	6	5	5	5	5x8	35,360	26,520	309,400	SNC data
C&I Trades	6	6	5	5	5	5x8	35,360	26,520	309,400	SNC data
Labourers	6	6	5	5	5	5x8	24,260	18,195	212,275	SNC data
Apprentices	6	5	4	3	2	5x8	27,520	20,640	96,320	SNC data
Facilities Manager	1	1	1	1	1	5x8	33,912	25,434	59,346	glassdoor.co.uk
Procurement Manager	1	1	1	1	1	5x8	50,000	37,500	87,500	glassdoor.co.uk - used lower rate as it is permanent, not project based

Operating Staff Costs

No of Trains 1

Role	No	Number - scaled to trains					Rate	Overhead and/or Shift Premium	Total Salary (Specified trains)	Note
Buyers	2	2	2	1	1	5x8	45,465	34,099	79,564	SNC data
Expediters	2	2	1	1	0	5x8	47,513	35,635	-	SNC data
Stores Manager	1	1	1	1	0	5x8	45,000	33,750	-	SNC data
Stores Keeper	6	6	5	5	5	4x10 shift rotation	30,000	37,500	337,500	SNC data
Drivers	6	6	5	5	5	4x10 shift rotation	24,000	30,000	270,000	SNC data
Quality Assurance Engineer	1	1	1	1	1	5x8	57,000	42,750	99,750	SNC data
Quality Control Technicians	6	6	5	5	5	4x10 shift rotation	42,320	52,900	476,100	SNC data
Reservoir Team										
Reservoir Manager	1	1	1	1	1	5x8	77,000	57,750	134,750	glassdoor.co.uk
Reservoir Engineer	1	1	1	1	1	5x8	50,903	38,177	89,080	glassdoor.co.uk
Injection Engineer	1	1	1	1	1	5x8	44,837	33,628	78,465	shell - glassdoor.co.uk
Data Managers	1	1	1	1	1	5x8	36,449	27,337	63,786	glassdoor.co.uk
Injection Chemist	0.5	0.5	0.5	0.5	0.5	5x8	45,000	33,750	39,375	glassdoor - range from 27k for chemist to 55k for offshore production chemist
Injection Geologist	0.5	0.5	0.5	0.5	0.5	5x8	46,000	34,500	40,250	glassdoor.co.uk - senior petroleum geologist
Drilling/Workover Manager	1	1	1	1	1	5x8	100,000	75,000	175,000	glassdoor - BP
Drilling/Workover Engineer	0.5	0.5	0.5	0.5	0.5	5x8	51,889	38,917	45,403	glassdoor avg
Geo-physicist	0.5	0.5	0.5	0.5	0.5	5x8	65,212	48,909	57,061	BP average - glassdoor
Reservoir Physicist	0.5	0.5	0.5	0.5	0.5	5x8	50,903	38,177	44,540	Reservoir engineer - no good data on reservoir physicist
									-	
Executive/Sr. Management										
Chairman	1	1	1	1	1	part-time	200,000	150,000	350,000	Extrapolated form EPH and power company published data
Non-Executive Directors	2	2	2	1	1	part-time	150,000	112,500	262,500	Extrapolated form EPH and power company published data
Managing Director	1	1	1	1	1	5x8	400,000	400,000	800,000	EPH
CFO	1	1	1	1	1	5x8	330,000	330,000	660,000	EPH
Company Secretary	1	1	1	1	1	5x8	200,000	200,000	400,000	Extrapolated form EPH and power company published data
Commercial Director	1	1	1	1	1	5x8	150,000	150,000	300,000	Extrapolated form EPH and power company published data
Traders	2	2	2	1	1	5x8	67,000	50,250	117,250	glassdoor avg
Economist	1	1	1	1	1	5x8	63,345	47,509	110,854	glassdoor - senior economist
								-	-	
Administration										
IT Technician	1	1	1	1	1	5x8	30,000	22,500	52,500	prior project - estimate
Human Resources Generalist	2	2	2	1	1	5x8	33,443	25,082	58,525	glassdoor
Payroll Clerk	1	1	1	1	1	5x8	18,270	13,703	31,973	glassdoor
Accountant / Accounts Payable	5	4	3	2	2	5x8	38,473	28,855	134,656	glassdoor
Accounts Payable	5	4	3	2	2	5x8	21,000	15,750	73,500	glassdoor
Administrator	2	2	2	1	1	5x8	18,778	14,084	32,862	glassdoor
Document Control Specialist/Information	1	1	1	1	1	5x8	24,000	18,000	42,000	prior project - estimate
	199.5	181.5	153.5	126.5	105.5				10,377,942	

Overhead and shift premium for shift workers = 2.25

Overhead for day workers = 1.75

Source for Staffing Levels - Org Chart 181869-0001-T-EM-REP-AAA-00-00005 Attachment 1

Consumables Costs

Trains	1	change on cover sheet only
Operating Conditions	24.00	
Days/yr	365.00	

Consumables	Amount	Unit	Note	Cost per uni		Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9
						73%	84%	87%	95%	95%	84%	96%	96%	87%
CCGT				USD	GBP									
Ammonia - SCR	302	kg/hr	previous project/ vendor quotation	0.0702	0.05	106,682	122,690	126,442	126,442	126,442	126,442	126,442	126,442	126,442
Lube Oil - GT	0.67	ltr/hr	previous project/ vendor quotation	2.3518	1.84	7,929	9,119	9,398	9,398	9,398	9,398	9,398	9,398	9,398
Lube Oil - ST	0.3	ltr/hr	previous project/ vendor quotation	2.3518	1.84	3,550	4,083	4,208	4,208	4,208	4,208	4,208	4,208	4,208
HCl - Demin Package	3	Tonne/yr	2014/11/03/9834809/us-hcl-market-range-	200	156.67	600	600	600	600	600	600	600	600	600
NaOH - Demin Package	17	Tonne/yr	previous project/ vendor quotation	1207.54	945.96	11,792	13,562	13,976	13,976	13,976	13,976	13,976	13,976	13,976
Oxygen Scavenger - Boiler Feedw	2	m3/yr	previous project/ vendor quotation	5008.7	3,923.68	5,754	6,618	6,820	6,820	6,820	6,820	6,820	6,820	6,820
Phosphate	9	m3/yr	previous project/ vendor quotation	4770	3,736.69	24,661	28,361	29,228	29,228	29,228	29,228	29,228	29,228	29,228
Alkali	131	m3/yr	Potassium Hydroxide KOH vendor quote) - density factor = 1.99	1592	1,247.13	119,800	137,777	141,990	141,990	141,990	141,990	141,990	141,990	141,990
Corrosion Inhibitor	66	m3/yr	previous project/ vendor quotation	7495.5	5,871.78	284,176	326,819	336,812	336,812	336,812	336,812	336,812	336,812	336,812
Antifreeze	0			8.1003	6.35	-	-	-	-	-	-	-	-	-
CCS														
Fresh Engineered Amine	1,589	Te/yr	previous project/ vendor quotation	1,992	1,560	1,818,263	2,091,104	2,155,047	2,155,047	2,155,047	2,155,047	2,155,047	2,155,047	2,155,047
NaOH (TRU, IX)	1651	Te/yr	previous project/ vendor quotation	1207.54	945.96	1,145,228	1,317,076	1,357,351	1,357,351	1,357,351	1,357,351	1,357,351	1,357,351	1,357,351
H2SO4 (Acid Wash)	313	Te/yr	previous project/ vendor quotation	318.6	249.58	57,284	65,880	67,894	67,894	67,894	67,894	67,894	67,894	67,894
Water Treatment														
NaOH	1729	Tonne/yr	previous project/ vendor quotation	1207.54	945.96	1,199,333	1,379,300	1,421,478	1,421,478	1,421,478	1,421,478	1,421,478	1,421,478	1,421,478
H2SO4	966	Tonne/yr	previous project/ vendor quotation	318.6	248.91	176,317	202,774	208,975	208,975	208,975	208,975	208,975	208,975	208,975
Methanol	541	Tonne/yr	online price	1,200.00	940.05	372,925	428,885	442,000	442,000	442,000	442,000	442,000	442,000	442,000
Acetic Acid	735	Tonne/yr	online price	600.00	470.02	253,327	291,341	300,249	300,249	300,249	300,249	300,249	300,249	300,249
Sodium Bicarbonate	2369	Tonne/yr	online price	200.00	156.67	272,169	313,009	322,581	322,581	322,581	322,581	322,581	322,581	322,581
Phosphoric Acid	803	Tonne/yr	online price	800.00	626.70	369,019	424,393	437,370	437,370	437,370	437,370	437,370	437,370	437,370
Anti-Scalant	60	Tonne/yr	previous project/ vendor quotation	275.4	215.74	9,492	10,916	11,250	11,250	11,250	11,250	11,250	11,250	11,250
Offshore														
Diesel - Gensets	41	ltr/hr	Continuous		1.2	430,992	430,992	430,992	430,992	430,992	430,992	430,992	430,992	430,992
Diesel - Gensets	1603	ltr/hr	30 mins per week		1.2	50,014	50,014	50,014	50,014	50,014	50,014	50,014	50,014	50,014
Nitrogen - repressurise wells	93	kg/well	1 well per month	33.61036	26.33	29,384	29,384	29,384	29,384	29,384	29,384	29,384	29,384	29,384
Well Washing (7 days)	42	m3/hr	Wash water injection rate 41.7m3/hr	incl in staff costs			-	-	-	-	-	-	-	-
Compression														
Tracer	0.5	Te/yr	Methyl Mercaptan - vendor price online	15,876	12,437	4,560	5,244	5,404	5,404	5,404	5,404	5,404	5,404	5,404
			*small package price - need bulk price)											
Total Consumables						6,753,252	7,689,941	7,909,464	7,909,464	7,909,464	7,909,464	7,909,464	7,909,464	7,909,464

CCGT + 50% Water Tratment						1,891,237	2,174,938	2,241,426	2,241,426	2,241,426	2,241,426	2,241,426	2,241,426	2,241,426
CCC + 50% Water Treatment						4,351,626	5,004,614	5,157,648	5,157,648	5,157,648	5,157,648	5,157,648	5,157,648	5,157,648
Offshore						510,389	510,389	510,389	510,389	510,389	510,389	510,389	510,389	510,389
Total Consumables						6,753,252	7,689,941	7,909,464	7,909,464	7,909,464	7,909,464	7,909,464	7,909,464	7,909,464
Check						-	-	-	-	-	-	-	-	-

Consumables Utilities Schedule: 181869-0001-T-EM-LST-AAA-00-00001

Forex 1.27653

Alkali density calc = m3 to kg
1.98 g/cm3
=1.98T/m3

Tracer = Methyl Mercaptan
Internet price = US$35/lb
500 kg/yr * US$35/lb * 0.4536 kg/lb
Other Lube Oils not included
Diesel for tests
Genset = 2.68MWx200gxkwhr = @536kg/hr = 643ltr/hr per train
Fire Pumps = 600kw @ 240 ltr/hr x 4

Tests = 30 minutes per week = .5*32 = 16 hr/year

Consumables Costs

Trains	
Operating Conditions	
Days/yr	

Consumables	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15	Year 16	Year 17	Year 18	Year 19	Year 20	Year 21	Year 22	Year 23	Year 24	Year 25
	96%	96%	85%	96%	96%	88%	96%	96%	84%	96%	96%	88%	95%	95%	83%	94%
CCGT																
Ammonia - SCR	126,442	126,442	126,442	126,442	126,442	126,442	126,442	126,442	126,442	126,442	126,442	126,442	126,442	126,442	126,442	126,442
Lube Oil - GT	9,398	9,398	9,398	9,398	9,398	9,398	9,398	9,398	9,398	9,398	9,398	9,398	9,398	9,398	9,398	9,398
Lube Oil - ST	4,208	4,208	4,208	4,208	4,208	4,208	4,208	4,208	4,208	4,208	4,208	4,208	4,208	4,208	4,208	4,208
HCl - Demin Package	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600
NaOH - Demin Package	13,976	13,976	13,976	13,976	13,976	13,976	13,976	13,976	13,976	13,976	13,976	13,976	13,976	13,976	13,976	13,976
Oxygen Scavenger - Boiler Feedwa	6,820	6,820	6,820	6,820	6,820	6,820	6,820	6,820	6,820	6,820	6,820	6,820	6,820	6,820	6,820	6,820
Phosphate	29,228	29,228	29,228	29,228	29,228	29,228	29,228	29,228	29,228	29,228	29,228	29,228	29,228	29,228	29,228	29,228
Alkali	141,990	141,990	141,990	141,990	141,990	141,990	141,990	141,990	141,990	141,990	141,990	141,990	141,990	141,990	141,990	141,990
Corrosion Inhibitor	336,812	336,812	336,812	336,812	336,812	336,812	336,812	336,812	336,812	336,812	336,812	336,812	336,812	336,812	336,812	336,812
Antifreeze	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CCS																
Fresh Engineered Amine	2,155,047	2,155,047	2,155,047	2,155,047	2,155,047	2,155,047	2,155,047	2,155,047	2,155,047	2,155,047	2,155,047	2,155,047	2,155,047	2,155,047	2,155,047	2,155,047
NaOH (TRU, IX)	1,357,351	1,357,351	1,357,351	1,357,351	1,357,351	1,357,351	1,357,351	1,357,351	1,357,351	1,357,351	1,357,351	1,357,351	1,357,351	1,357,351	1,357,351	1,357,351
H2SO4 (Acid Wash)	67,894	67,894	67,894	67,894	67,894	67,894	67,894	67,894	67,894	67,894	67,894	67,894	67,894	67,894	67,894	67,894
Water Treatment																
NaOH	1,421,478	1,421,478	1,421,478	1,421,478	1,421,478	1,421,478	1,421,478	1,421,478	1,421,478	1,421,478	1,421,478	1,421,478	1,421,478	1,421,478	1,421,478	1,421,478
H2SO4	208,975	208,975	208,975	208,975	208,975	208,975	208,975	208,975	208,975	208,975	208,975	208,975	208,975	208,975	208,975	208,975
Methanol	442,000	442,000	442,000	442,000	442,000	442,000	442,000	442,000	442,000	442,000	442,000	442,000	442,000	442,000	442,000	442,000
Acetic Acid	300,249	300,249	300,249	300,249	300,249	300,249	300,249	300,249	300,249	300,249	300,249	300,249	300,249	300,249	300,249	300,249
Sodium Bicarbonate	322,581	322,581	322,581	322,581	322,581	322,581	322,581	322,581	322,581	322,581	322,581	322,581	322,581	322,581	322,581	322,581
Phosphoric Acid	437,370	437,370	437,370	437,370	437,370	437,370	437,370	437,370	437,370	437,370	437,370	437,370	437,370	437,370	437,370	437,370
Anti-Scalant	11,250	11,250	11,250	11,250	11,250	11,250	11,250	11,250	11,250	11,250	11,250	11,250	11,250	11,250	11,250	11,250
Offshore																
Diesel - Gensets	430,992	430,992	430,992	430,992	430,992	430,992	430,992	430,992	430,992	430,992	430,992	430,992	430,992	430,992	430,992	430,992
Diesel - Gensets	50,014	50,014	50,014	50,014	50,014	50,014	50,014	50,014	50,014	50,014	50,014	50,014	50,014	50,014	50,014	50,014
Nitrogen - repressurise wells	29,384	29,384	29,384	29,384	29,384	29,384	29,384	29,384	29,384	29,384	29,384	29,384	29,384	29,384	29,384	29,384
Well Washing (7 days)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Compression																
Tracer	5,404	5,404	5,404	5,404	5,404	5,404	5,404	5,404	5,404	5,404	5,404	5,404	5,404	5,404	5,404	5,404
Total Consumables	7,909,464	7,909,464	7,909,464	7,909,464	7,909,464	7,909,464	7,909,464	7,909,464	7,909,464	7,909,464	7,909,464	7,909,464	7,909,464	7,909,464	7,909,464	7,909,464

CCGT + 50% Water Tratment	2,241,426	2,241,426	2,241,426	2,241,426	2,241,426	2,241,426	2,241,426	2,241,426	2,241,426	2,241,426	2,241,426	2,241,426	2,241,426	2,241,426	2,241,426	2,241,426
CCC + 50% Water Treatment	5,157,648	5,157,648	5,157,648	5,157,648	5,157,648	5,157,648	5,157,648	5,157,648	5,157,648	5,157,648	5,157,648	5,157,648	5,157,648	5,157,648	5,157,648	5,157,648
Offshore	510,389	510,389	510,389	510,389	510,389	510,389	510,389	510,389	510,389	510,389	510,389	510,389	510,389	510,389	510,389	510,389
Total Consumables	7,909,464	7,909,464	7,909,464	7,909,464	7,909,464	7,909,464	7,909,464	7,909,464	7,909,464	7,909,464	7,909,464	7,909,464	7,909,464	7,909,464	7,909,464	7,909,464
Check	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Consumables Utilities Schedule: 18
Forex

Alkali density calc = m3 to kg
1.98 g/cm3
=1.98T/m3

Tracer = Methyl Mercaptan
Internet price = US$35/lb
500 kg/yr * US$35/lb * 0.4536 kg/lb
Other Lube Oils not included
Diesel for tests
Genset = 2.68MWx200gxkwhr = @
Fire Pumps = 600kw @ 240 ltr/hr x

Tests = 30 minutes per week = .5*3

Maintenance Routine

	Activity	Frequency	Duration	Outage	Comments	Estimate per Occurance per Train	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15	Year 16	Year 17	Year 18	Year 19	Year 20	Year 21	Year 22	Year 23	Year 24
						Planned Outage Time	28	7	35	7	7	49	7	7	40	7	7	49	7	7	35	7	7	49	7	7	35	7	7	49
Trains							7.7%	1.9%	9.6%	1.9%	1.9%	13.4%	1.9%	1.9%	11.0%	1.9%	1.9%	13.4%	1.9%	1.9%	9.6%	1.9%	1.9%	13.4%	1.9%	1.9%	9.6%	1.9%	1.9%	13.4%
Power Generation																														
Power Generation	Initial Inspection	1000 hrs	3 weeks	21 days		£127,267	127,267	-																						
Power Generation	Gas Turbine Combustion Inspection	8000 hrs	10 days	7 days		£310,603	310,603	310,603	310,603	310,603	310,603	310,603	310,603	310,603	310,603	310,603	310,603	310,603	310,603	310,603	310,603	310,603	310,603	310,603	310,603	310,603	310,603	310,603	310,603	310,603
Power Generation	HRSG Internal Inspection	8000 hrs	5 days	See above		£280,302	280,302	280,302	280,302	280,302	280,302	280,302	280,302	280,302	280,302	280,302	280,302	280,302	280,302	280,302	280,302	280,302	280,302	280,302	280,302	280,302	280,302	280,302	280,302	280,302
Power Generation	Generator Inspection	8000 hrs	1 day	See above	Requires disconnect of machine in order to carry out preventative maintenance	£256,060	256,060	256,060	256,060	256,060	256,060	256,060	256,060	256,060	256,060	256,060	256,060	256,060	256,060	256,060	256,060	256,060	256,060	256,060	256,060	256,060	256,060	256,060	256,060	256,060
Power Generation	Steam Turbine Minor Inspection	16,000 hrs	2 days	2 days		£262,121	-	262,121	-	262,121	-	262,121	-	262,121	-	262,121	-	262,121	-	262,121	-	262,121	-	262,121	-	262,121	-	262,121	-	262,121
Power Generation	Generator Inspection	16,000 hrs	2 days	See above	Machine disconnected to allow diagnostics onto electrical terminals	£262,121	-	262,121	-	262,121	-	262,121	-	262,121	-	262,121	-	262,121	-	262,121	-	262,121	-	262,121	-	262,121	-	262,121	-	262,121
Power Generation	Gas Turbine Hot Gas Path Inspection	24,000 hrs	40 days	35 days		£4,242,414	-	-	4,242,414	-	-	4,242,414	-	-	4,242,414	-	-	4,242,414	-	-	4,242,414	-	-	4,242,414	-	-	4,242,414	-	-	4,242,414
Power Generation	Generator Internal Inspection	24,000 hrs	5 days	See above		£280,302	-	-	280,302	-	-	280,302	-	-	280,302	-	-	280,302	-	-	280,302	-	-	280,302	-	-	280,302	-	-	280,302
Power Generation	Gas Turbine Major Inspection / Overhaul	48,000 hrs	49 - 57 days	49 days		£8,345,440	-	-	-	-	-	8,345,440	-	-	-	-	-	8,345,440	-	-	-	-	-	8,345,440	-	-	-	-	-	8,345,440
Power Generation	Steam Turbine Major Inspection	48,000 hrs	3 weeks	See above		£1,127,267	-	-	-	-	-	1,127,267	-	-	-	-	-	1,127,267	-	-	-	-	-	1,127,267	-	-	-	-	-	1,127,267
Power Generation	Generator Rotor Removal Inspection	48,000 hrs	10 days	See above		£1,060,603	-	-	-	-	-	1,060,603	-	-	-	-	-	1,060,603	-	-	-	-	-	1,060,603	-	-	-	-	-	1,060,603
Power Generation	Steam Turbine Overhaul	100,000 hrs	7 weeks	7 weeks		£773,533	-	-	-	-	-	-	-	-	-	-	-	773,533	-	-	-	-	-	-	-	-	-	-	-	773,533
Carbon Capture																														
Carbon Capture	In General - will follow the maintenance routine set by the Power Generation Unit																													
	KEY EQUIPMENT ITEM																													
Carbon Capture	Blower	Same as compressor																												
Carbon Capture	Process Licensor	Yearly	100 hours																											
Carbon Capture	CO_2 Compressor	Monthly	4 hours		Checking automatic cut-in of the auxiliary and emergency oil systems Draining condensed water and oil sludge from the oil reservoir Servicing the filter elements Checking the leakage current arrestor																									
Carbon Capture	CO_2 Compressor - oil sampling and lab analysis	500 hours	1 hour																											
Carbon Capture	CO_2 Compressor - external inspection	Yearly	5 days		Duration includes OEM report write up	£13,734	13,734	13,734	13,734	13,734	13,734	13,734	13,734	13,734	13,734	13,734	13,734	13,734	13,734	13,734	13,734	13,734	13,734	13,734	13,734	13,734	13,734	13,734	13,734	13,734
Carbon Capture	CO_2 Compressor - internal inspection	3 years	5 days			£13,734	-	-	13,734	-	-	13,734	-	-	13,734	-	-	13,734	-	-	13,734	-	-	13,734	-	-	13,734	-	-	13,734
Carbon Capture	CO_2 Compressor - overhaul	6 years	10 days		Replacement of Bearings and Seals	£247,739	-	-	-	-	-	247,739	-	-	-	-	-	247,739	-	-	-	-	-	247,739	-	-	-	-	-	247,739
Carbon Capture	Dehydration Package - Mole Sieve Replacement	3 Years	5 days			£202,881	-	-	202,881	-	-	202,881	-	-	202,881	-	-	202,881	-	-	202,881	-	-	202,881	-	-	202,881	-	-	202,881
Utilities	Waste Water Treatment Plant - Membrane Replacement 1	2 Years				See Peterhead OPEX model																								
Utilities	Waste Water Treatment Plant - Membrane Replacement 2	5 Years				See Peterhead OPEX model																								
Utilities	ICSS	<HOLD>																												
Transport																														
Transport	Onshore Route Survey	2 weeks	1 day																											
Transport	Cathodic Protection Survey	Annually	1 day																											
Transport	Emergency Systems Check	Annually	1 day																											
Transport	Offshore Route Survey (side scan sonar)	5 years	1 week																											
Transport	Internal Inspection (Intelligent Pig Run)	5 Years																												
Transport	Overpressure Protection Devices	Annually	1 week		Typically PSVs are twinned and interlocked so that 1 can be removed for calibratic without stopping plant operation. Shutdown is only required for calibration of electronic devices.																									
Transport	Population Density Survey, Review of any Sensitive Proposed New Sites (e.g. Schools)	2 Years	4 weeks																											
Transport	Cathodic Protection Rectifier Maintenance	2 Months	1 day																											
Transport	Valve Maintenance and Inspection	6 Months																												
Transport	Leak test	5 Years			Schedule with Intelligent Pig Run.																									
	Overall pipeline maintenance				0.5% of Capex per Teesside	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000
Offshore																														
Offshore	Campaign Maintenance Visits	2 Month	8 days		Six campaign maintenance visits per year of 6-8 days duration with a crew of 12 (planned and unplanned maintenance c. 6000 manhours per year); additional visits for ad-hoc work	Using O&M Team and Sub-contracts																								
Offshore	Well Washing	1 per year per well	7 days		Only the well being washed is shutdown. Injection to continue with operating wells Spare well provided for each platform.	Using O&M Team and Sub-contracts																								
Offshore	Wireline logging suite (incl PNT, density, sonic, well bore integrity etc)	Every 10 years			Gather data on the reservoir, overburden and wellbore to reservoir models. Assume £50k/time - 2 times (after 10 year and after 20 years - wells re-drilled after ~ 15 years so will have wireline suite then)	£342,000	-	-	-	-	-	-	-	-	-	342,000	-	-	-	-	-	-	-	-	-	342,000	-	-	-	-
Offshore	Heavy Work Over	Every 15 years	Included in Year 16 - may be o		Intervention only required following failure within well.	£15,680,404	-	-	-	-	-	-	-	-	-	-	-	-	-	-		15,680,404	-	-	-	-	-	-	-	-
Monitoring	**BASE LINE**																													
Monitoring	Seabed sampling, ecosystem response monitoring geochemical analyses of water column	1-2 years prior to injection			Baseline sampling to understand background CO2 concentrations in the sediment and water column to benchmark any future surveys against. Data Source: IEAGHG Seafloor sampling - £5k/day when using existing vessel Geochemical survey - £10k when using existing vessel Ecosystem response monitoring - £100s per sample excluding processing and organism identification £10k for interpretation and reporting?	£114,000	114,000																							
Monitoring	Sidescan sonar survey; Chirps, boomers & pingers	1-2 years prior to injection			Baseline sidescan sonar survey to benchmark future surveys. Looking to detect any pre-existing bubble streams on seabed or around abandoned wellheads and map pock-marks. Data Source: IEAGHG Sidescan sonar £100k-200k/10km2 survey Storage complex 800 Chirps, boomers & pingers - <£100k	£228,000	228,000																							
Monitoring	Seismic survey (this is dependent on modelling results & could also include installation of permanent geophones though not in cost)	1-2 years prior to injection			Baseline survey required for 4D seismic Baseline to be storage complex 800km2; processing included + 10% interpretation (benchmarked from PGS 225km2 for BC36)	£8,690,792	8,690,792																							
Monitoring	Wireline logging suite (incl PNT, density, sonic, well bore integrity etc)	During drilling programme			Part of the drilling programme to gather data on the reservoir, overburden and wellbore for baseline update to reservoir models.	Note 4																								
Monitoring	Installation of Distributed Temperature Sensor (DTS), downhole and wellhead P/T gauge and flow meter	Permanent installation once wells drilled			DTS for real-time monitoring of temperature along the length of the wellbore. P/T gauge considered essential to ensure injection integrity & required under EU Storage Directive; flow meter for reporting.	Note 5																								
	DURING OPERATION																													
Monitoring	4D seismic survey	Every 5 years			For detection of any migration outwith storage site Data Source: PGS Assume survey cost per time - 4 times (after 5, 10, 15, 20)	£34,763,167	-	-	-	-	34,763,167	-	-	-	-	34,763,167	-	-	-	-	34,763,167	-	-	-	-	34,763,167	-	-	-	-
Monitoring	Chirps, boomers & pingers; sidescan sonar	Every 5 years			Looking to detect any bubble streams around abandoned wellheads, seabed or pock-marks. Data Source: IEAGHG Assume £100k/time - 4 times	£400,000	-	-	-	-	400,000	-	-	-	-	400,000	-	-	-	-	400,000	-	-	-	-	400,000	-	-	-	-
Monitoring	Seabed sampling, ecosystem response monitoring geochemical analyses of water column	Every 5 years			Looking to detect any evidence of elevated CO2 concentrations in sediment or water column which may indicate loss of containment. Data Source: IEAGHG Assume £50k/time - 4 times	£200,000	-	-	-	-	200,000	-	-	-	-	200,000	-	-	-	-	200,000	-	-	-	-	200,000	-	-	-	-
Monitoring	DTS, downhole and wellhead P/T gauge and flow meter readings	Continuous			Temperature, pressure and flow data to ensure injection integrity and update reservoir models.	Note 5																								
Monitoring	Data management	Continuous			To collate, manage, interpret and report on monitoring data.	Note 6																								
	POST CLOSURE																													
Monitoring	4D seismic survey	Every 5 years			For detection of any migration outwith storage site Assume survey cost per time - 5 times (after 0, 5, 10, 15, 20 years post closure)	£43,453,959																								
Monitoring	Chirps, boomers & pingers	Every 5 years			Looking to detect any bubble streams around abandoned wellheads, seabed or pock-marks. Data Source: IEAGHG Assume £100k/time - 4 times	£400,000																								
Monitoring	Seabed sampling, ecosystem response monitoring geochemical analyses of water column	Every 5 years			Looking to detect any evidence of elevated CO2 concentrations in sediment or water column which may indicate loss of containment. Data Source: IEAGHG Assume £50k/time - 4 times	£200,000																								
Monitoring	Data management	Continuous			To collate, manage, interpret and report on monitoring data.	Note 6																								
Regular Maintenance - materials							3,383,092	3,383,092	3,383,092	3,383,092	3,383,092	3,383,092	3,383,092	3,383,092	3,383,092	3,383,092	3,383,092	3,383,092	3,383,092	3,383,092	3,383,092	3,383,092	3,383,092	3,383,092	3,383,092	3,383,092	3,383,092	3,383,092	3,383,092	3,383,092

Maintenance Routine

				Planned Outage Time																									
						28	7	35	7	7	49	7	7	40	7	7	49	7	7	35	7	7	49	7	7	35	7	7	49
Trains						7.7%	1.9%	9.6%	1.9%	1.9%	13.4%	1.9%	1.9%	11.0%	1.9%	1.9%	13.4%	1.9%	1.9%	9.6%	1.9%	1.9%	13.4%	1.9%	1.9%	9.6%	1.9%	1.9%	13.4%
	Activity	Frequency	Duration	Outage	Comments	Estimate per Occurance per Train	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15	Year 16	Year 17	Year 18	Year 19	Year 20	Year 21	Year 22	Year 23	Year 24
Total Maintenance Cost						1 Train	14,813,850	6,178,033	10,393,121	6,178,033	41,016,958	21,698,412	5,653,791	6,178,033	10,393,121	41,883,200	5,653,791	22,471,945	5,653,791	6,178,033	45,756,289	21,858,437	5,653,791	21,698,412	5,653,791	41,883,200	10,393,121	6,178,033	5,653,791	22,471,945
CCGT	.5 of CCGT spares plus .5 of half of utilities spares (split with CCC)					1 train	3,178,611	3,575,585	7,574,059	3,575,585	3,051,344	18,631,611	3,051,344	3,575,585	7,574,059	3,575,585	3,051,344	19,405,144	3,051,344	3,575,585	7,574,059	3,575,585	3,051,344	18,631,611	3,051,344	3,575,585	7,574,059	3,575,585	3,051,344	19,405,144
CCC	.5 of CCC spares per year plus .5 of half of utilities spares (split with CCGT)					1 train	1,097,617	1,097,617	1,314,232	1,097,617	1,097,617	1,561,971	1,097,617	1,097,617	1,314,232	1,097,617	1,097,617	1,561,971	1,097,617	1,097,617	1,314,232	1,097,617	1,097,617	1,561,971	1,097,617	1,097,617	1,314,232	1,097,617	1,097,617	1,561,971
Pipelines						1 train	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000
Offshore						1 train	9,127,622	94,831	94,831	94,831	35,457,998	94,831	94,831	94,831	94,831	35,799,998	94,831	94,831	94,831	94,831	35,457,998	15,775,235	94,831	94,831	94,831	35,799,998	94,831	94,831	94,831	94,831

Notes:

1. Sources of Information:
   - CO_2 Pipeline Infrastructure, Report 2013/18, IEAGHG
   - Single-Shaft Combined-Cycle Power Generation System, Tomlinson and McCullough, GE Power Systems (GER-3767C)
   - PCCS-00-PT-AA-7704-00001, Basis of Design for the CCS Chain, Shell UK Limited
   - PCCS-00-PTD-AA-7704-00002, Basic Design and Engineering Package, Shell UK Limited
   - PCCS-00-MM-FA-3101-00001, Cost Estimate Report, Shell UK Limited

2. Key
   - SHUT DOWN REQUIRED
   - DOES NOT INTERFERE WITH OPERATION

3. Steam Turbine Operating Hours for Scheduled Maintenance assumes 80 normal starts per annum.

4. Included in drilling costs.

5. Included in well costs.

6. Included in O&M staff costs.

7. 3 years after installation or overhaul.

Source: 181869-0001-T-EM-REP-AAA-00-00005 Attachment 2

For Summary by AREA

		Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15	Year 16	Year 17	Year 18	Year 19	Year 20	Year 21	Year 22	Year 23	Year 24
CCGT	2 train	6,357,222	7,151,170	15,148,118	7,151,170	6,102,687	37,263,222	6,102,687	7,151,170	15,148,118	7,151,170	6,102,687	38,810,288	6,102,687	7,151,170	15,148,118	7,151,170	6,102,687	37,263,222	6,102,687	7,151,170	15,148,118	7,151,170	6,102,687	38,810,288
CCC	2 train	2,195,234	2,195,234	2,628,463	2,195,234	2,195,234	3,123,941	2,195,234	2,195,234	2,628,463	2,195,234	2,195,234	3,123,941	2,195,234	2,195,234	2,628,463	2,195,234	2,195,234	3,123,941	2,195,234	2,195,234	2,628,463	2,195,234	2,195,234	3,123,941
Pipelines	2 train	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000
Offshore	2 train	9,127,622	94,831	94,831	94,831	35,457,998	94,831	94,831	94,831	94,831	35,799,998	94,831	94,831	94,831	94,831	35,457,998	15,775,235	94,831	94,831	94,831	35,799,998	94,831	94,831	94,831	94,831
CCGT	3 train	9,535,832	10,726,755	22,722,177	10,726,755	9,154,031	55,894,832	9,154,031	10,726,755	22,722,177	10,726,755	9,154,031	58,215,433	9,154,031	10,726,755	22,722,177	10,726,755	9,154,031	55,894,832	9,154,031	10,726,755	22,722,177	10,726,755	9,154,031	58,215,433
CCC	3 train	3,292,851	3,292,851	3,942,695	3,292,851	3,292,851	4,685,912	3,292,851	3,292,851	3,942,695	3,292,851	3,292,851	4,685,912	3,292,851	3,292,851	3,942,695	3,292,851	3,292,851	4,685,912	3,292,851	3,292,851	3,942,695	3,292,851	3,292,851	4,685,912
Pipelines	3 train	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000
Offshore	3 train	9,127,622	94,831	94,831	94,831	35,457,998	94,831	94,831	94,831	94,831	35,799,998	94,831	94,831	94,831	94,831	35,457,998	15,775,235	94,831	94,831	94,831	35,799,998	94,831	94,831	94,831	94,831
CCGT	4 train - 2 offshore an	12,714,443	14,302,340	30,296,236	14,302,340	12,205,374	74,526,443	12,205,374	14,302,340	30,296,236	14,302,340	12,205,374	77,620,577	12,205,374	14,302,340	30,296,236	14,302,340	12,205,374	74,526,443	12,205,374	14,302,340	30,296,236	14,302,340	12,205,374	77,620,577
CCC	4 train	4,390,468	4,390,468	5,256,927	4,390,468	4,390,468	6,247,882	4,390,468	4,390,468	5,256,927	4,390,468	4,390,468	6,247,882	4,390,468	4,390,468	5,256,927	4,390,468	4,390,468	6,247,882	4,390,468	4,390,468	5,256,927	4,390,468	4,390,468	6,247,882
Pipelines	4 train	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000
Offshore	4 train	18,255,245	189,661	189,661	189,661	70,915,996	189,661	189,661	189,661	189,661	71,599,996	189,661	189,661	189,661	189,661	70,915,996	31,550,469	189,661	189,661	189,661	71,599,996	189,661	189,661	189,661	189,661
CCGT	5 train - 2 offshore an	15,893,054	17,877,925	37,870,295	17,877,925	15,256,718	93,158,054	15,256,718	17,877,925	37,870,295	17,877,925	15,256,718	97,025,721	15,256,718	17,877,925	37,870,295	17,877,925	15,256,718	93,158,054	15,256,718	17,877,925	37,870,295	17,877,925	15,256,718	97,025,721
CCC	5 train	5,488,085	5,488,085	6,571,159	5,488,085	5,488,085	7,809,853	5,488,085	5,488,085	6,571,159	5,488,085	5,488,085	7,809,853	5,488,085	5,488,085	6,571,159	5,488,085	5,488,085	7,809,853	5,488,085	5,488,085	6,571,159	5,488,085	5,488,085	7,809,853
Pipelines	5 train	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000	1,410,000
Offshore	5 train	18,255,245	189,661	189,661	189,661	70,915,996	189,661	189,661	189,661	189,661	71,599,996	189,661	189,661	189,661	189,661	70,915,996	31,550,469	189,661	189,661	189,661	71,599,996	189,661	189,661	189,661	189,661

* Assume double monitoring for 2 drill centres - not enough data to have exact figures for increase in area to survey.

Maintenance Routine

					7
Trains	1				1.9%
	Activity	Frequency	Duration	Outage	Year 25
Power Generation					
Power Generation	Initial Inspection	1000 hrs	3 weeks	21 days	
Power Generation	Gas Turbine Combustion Inspection	8000 hrs	10 days	7 days	310,603
Power Generation	HRSG Internal Inspection	8000 hrs	5 days	See above	280,302
Power Generation	Generator Inspection	8000 hrs	1 day	See above	256,060
Power Generation	Steam Turbine Minor Inspection	16,000 hrs	2 days	2 days	-
Power Generation	Generator Inspection	16,000 hrs	2 days	See above	-
Power Generation	Gas Turbine Hot Gas Path Inspection	24,000 hrs	40 days	35 days	-
Power Generation	Generator Internal Inspection	24,000 hrs	5 days	See above	-
Power Generation	Gas Turbine Major Inspection / Overhaul	48,000 hrs	49 - 57 days	49 days	-
Power Generation	Steam Turbine Major Inspection	48,000 hrs	3 weeks	See above	-
Power Generation	Generator Rotor Removal Inspection	48,000 hrs	10 days	See above	-
Power Generation	Steam Turbine Overhaul	100,000 hrs	7 weeks	7 weeks	-
Carbon Capture					
Carbon Capture	In General - will follow the maintenance routine set by the Power Generation Unit				
	KEY EQUIPMENT ITEM				
Carbon Capture	Blower	Same as compressor			
Carbon Capture	Process Licensor	Yearly	100 hours		
Carbon Capture	CO_2 Compressor	Monthly	4 hours		
Carbon Capture	CO_2 Compressor - oil sampling and lab analysis	500 hours	1 hour		
Carbon Capture	CO_2 Compressor - external inspection	Yearly	5 days		13,734
Carbon Capture	CO_2 Compressor - internal inspection	3 years	5 days		-
Carbon Capture	CO_2 Compressor - overhaul	6 years	10 days		-
Carbon Capture	Dehydration Package - Mole Sieve Replacement	3 Years	5 days		-
Utilities	Waste Water Treatment Plant - Membrane Replacement 1	2 Years			
Utilities	Waste Water Treatment Plant - Membrane Replacement 2	5 Years			
Utilities	ICSS	<HOLD>			
Transport					
Transport	Onshore Route Survey	2 weeks	1 day		
Transport	Cathodic Protection Survey	Annually	1 day		
Transport	Emergency Systems Check	Annually	1 day		
Transport	Offshore Route Survey (side scan sonar)	5 years	1 week		
Transport	Internal Inspection (Intelligent Pig Run)	5 Years			
Transport	Overpressure Protection Devices	Annually	1 week		
Transport	Population Density Survey, Review of any Sensitive Proposed New Sites (e.g. Schools)	2 Years	4 weeks		
Transport	Cathodic Protection Rectifier Maintenance	2 Months	1 day		
Transport	Valve Maintenance and Inspection	6 Months			
Transport	Leak test	5 Years			
	Overall pipeline maintenance				1,410,000
Offshore					
Offshore	Campaign Maintenance Visits	2 Month	8 days		
Offshore	Well Washing	1 per year per well	7 days		
Offshore	Wireline logging suite (incl PNT, density, sonic, well bore integrity etc)	Every 10 years			-
Offshore	Heavy Work Over	Every 15 years	Included in Year 16 - may be o		-
Monitoring	**BASE LINE**				
Monitoring	Seabed sampling, ecosystem response monitoring geochemical analyses of water column	1-2 years prior to injection			
Monitoring	Sidescan sonar survey; Chirps, boomers & pingers	1-2 years prior to injection			
Monitoring	Seismic survey (this is dependent on modelling results & could also include installation of permanent geophones though not in cost)	1-2 years prior to injection			
Monitoring	Wireline logging suite (incl PNT, density, sonic, well bore integrity etc)	During drilling programme			
Monitoring	Installation of Distributed Temperature Sensor (DTS), downhole and wellhead P/T gauge and flow meter	Permanent installation once wells drilled			
	DURING OPERATION				
Monitoring	4D seismic survey	Every 5 years			
Monitoring	Chirps, boomers & pingers; sidescan sonar	Every 5 years			
Monitoring	Seabed sampling, ecosystem response monitoring geochemical analyses of water column	Every 5 years			
Monitoring	DTS, downhole and wellhead P/T gauge and flow meter readings	Continuous			
Monitoring	Data management	Continuous			
	POST CLOSURE				
Monitoring	4D seismic survey	Every 5 years			43,453,959
Monitoring	Chirps, boomers & pingers	Every 5 years			400,000
Monitoring	Seabed sampling, ecosystem response monitoring geochemical analyses of water column	Every 5 years			200,000
Monitoring	Data management	Continuous			
Regular Maintenance - materials					3,383,092

Maintenance Routine

					7
Trains	1				1.9%
	Activity	Frequency	Duration	Outage	Year 25
Total Maintenance Cost					49,707,750
CCGT	.5 of CCGT spares plus .5 of half of utilities spares (split with CCC)				3,051,344
CCC	.5 of CCC spares per year plus .5 of half of utilities spares (split with CCGT)				1,097,617
Pipelines					1,410,000
Offshore					44,148,790

Notes:

1. Sources of Information:
   - CO_2 Pipeline Infrastructure, Report 2013/18, IEAGHG
   - Single-Shaft Combined-Cycle Power Generation System, Tomlinson and McCullough, GE Pow
   - PCCS-00-PT-AA-7704-00001, Basis of Design for the CCS Chain, Shell UK Limited
   - PCCS-00-PTD-AA-7704-00002, Basic Design and Engineering Package, Shell UK Limited
   - PCCS-00-MM-FA-3101-00001, Cost Estimate Report, Shell UK Limited

6,102,687

2. Key — SHUT DOWN REQUIRED (hatched box) 2,195,234

1,410,000

DOES NOT INTERFERE WITH OPERATION (dotted box) 44,148,790

3. Steam Turbine Operating Hours for Scheduled Maintenance assumes 80 normal starts per annum. 9,154,031

3,292,851

4. Included in drilling costs. 1,410,000

44,148,790

5. Included in well costs.

12,205,374

6. Included in O&M staff costs. 4,390,468

1,410,000

7. 3 years after installation or overhaul. 88,297,580

15,256,718

Source: 181869-0001-T-EM-REP-AAA-00-00005 Attachment 2 5,488,085

1,410,000

88,297,580

2 years Spares

USD	1.3		Scale up Factor
EUR	1.16		1.29

Area	Peterhead Spares	GBP	Scale up Factor	Scale up	Note:
CCC					
Columns - Metallic	3,606	2,774	1.05	2,913	Wuxi Quotation
Vessels & Drums	854	854	1.08	922	Cordell Quotation
API Pumps	136,500	136,500	1.39	189,735	SPX Quotation
Caustic Transfer Pumps	7,987	7,987	1.20	9,584	Kinderjane Quotation
ANSI Pumps	28,700	28,700	1.39	39,893	SPX Quotation
Booster Fan	18,430	15,888	1.30	20,654	Howdens Quotation
CO2 Compressor	192,000	165,517	1.30	215,172	MAN-Diesel Quotation
Gas-Gas HE	7,559	7,559	1.00	7,559	Howden Quotation
Shell & Tube HE	7,530	7,530	1.29	9,702	Hunt Thermal Tech quotation
Plate and Frame HE	337,442	290,898	1.08	314,170	Alfa Laval - 2%
Vacuum Package	25,080	21,621	1.29	27,891	Flowserve Quotation
Ion Exchange			1.29	-	
Thermal Recovery Unit			1.29	-	
Instrument Air Compressor	149,477	149,477	1.29	192,825	HPC Quotation
WWTP	166,200	166,200	1.29	214,398	Ondeo quotation
Site Fab Tanks	15,454	15,454	1.09	16,845	Motherwell Bridge Quotation
Other					
Power		175,162,672	2%	3,503,253	
Offshore		9,483,063	2%	189,661	
Utilities		90,550,259	2%	1,811,005	
Total 2 year Spares				**6,766,184**	
Annual Cost				**3,383,092**	

= ~2% of equipment cost

	1 train/yr	2 train/yr	3 train/yr	4 train/yr	5 train/yr
CCGT	2,204,378	4,408,756	6,613,134	8,817,512	11,021,890
CCC	1,083,883	2,167,766	3,251,649	4,335,533	5,419,416
Offshore	94,831	94,831	94,831	189,661	189,661

Utilities Costs

Trains	1
Plant Operating	24
Days	365

Availability

Utilities		Unit	1 train	5 trains	USD	GBP	Note	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
								73%	84%	87%	95%	95%	84%
Utilities													
Towns Water	rated	kg/hr	9,321			0.0008	- https://www.nwl.co.uk/_assets/documents/NWL_Indicative_Wholesale_Oct_2016.pdf	46,762	53,779	55,423	60,475	60,634	53,456
Raw water	normal	Te/hr	1,761	8,806		0.014	- https://www.gov.uk/government/publications/abstraction-charges-scheme-april-2014-to-march-2015	158,385	182,152	187,722	204,831	205,371	181,057
Hydrogen	normal	kg/hr	0.23		1.40	1.10	https://en.wikipedia.org/wiki/Hydrogen_economy	1,620	1,863	1,920	2,095	2,101	1,852
Nitrogen	normal	kg/hr	203		0.65	0.51	per start per year	1,247	1,247	1,247	1,247	1,247	1,247
CO2 - gas turbine fire fighting	intermittent	kg/hr	2,899		0.70	0.55	Plan to replace CO2 every 5 years	1,600	-	-	-	-	1,600
Total Utilities								209,615	239,042	246,313	268,649	269,354	239,212

UDS/GBP	1.27653

CO2 - 1kg/hr = 1.9772 Nm3/hr
Plan to replace CO2 every 5 years

Nitrogen = 3.06 kg per gallon liquid @ $2.00 per gallon (not enough to order bulk)
Price = 0.50/3.06
0.163399

Utilities Costs

Trains	1
Plant Operating	24
Days	365

Utilities		Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15	Year 16	Year 17	Year 18	Year 19	Year 20	Year 21	Year 22	Year 23	Year 24
		96%	96%	87%	96%	96%	85%	96%	96%	88%	96%	96%	84%	96%	96%	88%	95%	95%	83%
Utilities																			
Towns Water	rated	60,953	61,112	55,379	61,208	61,272	53,934	61,272	61,208	56,252	61,112	61,049	53,647	60,953	60,921	55,997	60,794	60,570	53,041
Raw water	normal	206,451	206,991	187,571	207,315	207,531	182,677	207,531	207,315	190,530	206,991	206,775	181,705	206,451	206,343	189,666	205,911	205,155	179,653
Hydrogen	normal	2,112	2,118	1,919	2,121	2,123	1,869	2,123	2,121	1,949	2,118	2,115	1,859	2,112	2,111	1,940	2,107	2,099	1,838
Nitrogen	normal	1,247	1,247	1,247	1,247	1,247	1,247	1,247	1,247	1,247	1,247	1,247	1,247	1,247	1,247	1,247	1,247	1,247	1,247
CO2 - gas turbine fire fighting	intermittent	-	-	-	-	1,600	-	-	-	-	1,600	-	-	-	-	1,600	-	-	-
Total Utilities		270,764	271,469	246,116	271,892	273,774	239,727	272,174	271,892	249,979	273,069	271,187	238,458	270,764	270,623	250,451	270,059	269,072	235,780

UDS/GBP	1.27653

CO2 - 1kg/hr = 1.9772 Nm3/hr
Plan to replace CO2 every 5 years

Utilities Costs

Trains	1
Plant Operating	24
Days	365

Utilities		Year 25
		94%
Utilities		
Towns Water	rated	60,060
Raw water	normal	203,427
Hydrogen	normal	2,081
Nitrogen	normal	1,247
CO2 - gas turbine fire fighting	intermittent	-
Total Utilities		266,816

UDS/GBP	1.27653

CO2 - 1kg/hr = 1.9772 Nm3/hr
Plan to replace CO2 every 5 years

Fuel Gas Cost

Trains	1	
Plant Operating	24	
Days	365	

Availability

Fuel Gas								Year 1	Year 2	Year 3
								73%	84%	87%
		Unit	1 train	5 trains	USD	GBP	Note			
Fuel Gas	rated	Nm^3/hr	113,400	567,000		0.18	UK historical average (6 months) wholesa	133,318,897	153,324,203	158,012,655
							can be changed on Summary tab			
Total Utilities								133,318,897	153,324,203	158,012,655

1mmbtu/hr = 27.49 m^3/hr = 20.62 kg/hr
NASDAQ

3.022
0.109930884 mmbtu

UK historical average wholesale gas price

One **therm** is equal to about 105.5 megajoules, 25,200 kilocalories or 29.3 kilowatt-hours. One **therm** can also be provided by about 96.7 cubic feet (2.74 **m3**) of natural gas.

Natural gas 2 year average = 39.24/Therm	http://www.energybrokers.co.uk/gas/historic-price-data-graph.htm	0.143211679	Includes Historic Lows
Natural Gas 6 month average	https://www.ofgem.gov.uk/data-portal/wholesale-market-indicators	0.170194647	generally low
Natural Gas 5 year average	https://www.ofgem.gov.uk/data-portal/wholesale-market-indicators	0.186167883	Includes historic Highs and lows

Andrew NG Cost

0.035315 **MMBTU**	1 m3 to mmbtu	
$4		
	0.14126	USD/m3
	0.11	GBP/m3

UDS/GBP	1.27653

Fuel Gas Cost

Trains	1
Plant Operating	24
Days	365

Fuel Gas		Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13
		95%	95%	84%	96%	96%	87%	96%	96%	85%	96%
Fuel Gas	rated	172,414,234	172,868,758	152,402,701	173,777,807	174,232,332	157,885,637	174,505,047	174,686,857	153,766,275	174,686,857
Total Utilities		172,414,234	172,868,758	152,402,701	173,777,807	174,232,332	157,885,637	174,505,047	174,686,857	153,766,275	174,686,857

<img src='https://geo.yahoo.com/b?s=2114717799&t=
1mmbtu/hr = 27.49 m^3/hr = 20.62 kg/hr
NASDAQ
3.022
0.109930884 mmbtu

UK historical average wholesale gas price

One **therm** is equal to about 105.5 me
Natural gas 2 year average = 39.24/Therm
Natural Gas 6 month average
Natural Gas 5 year average

Andrew NG Cost

0.035315 **MMBTU** 1 m3 to mm
$4
0.14126 USD/m3
0.11 GBP/m3

UDS/GBP	1.27653

Fuel Gas Cost

Trains	1
Plant Operating	24
Days	365

Fuel Gas		Year 14	Year 15	Year 16	Year 17	Year 18	Year 19	Year 20	Year 21	Year 22	Year 23
		96%	88%	96%	96%	84%	96%	96%	88%	95%	95%
Fuel Gas	rated	174,505,047	160,376,182	174,232,332	174,050,522	152,948,131	173,777,807	173,686,903	159,648,943	173,323,283	172,686,949
Total Utilities		174,505,047	160,376,182	174,232,332	174,050,522	152,948,131	173,777,807	173,686,903	159,648,943	173,323,283	172,686,949

<img src='https://geo.yahoo.com/b?s=2114717799&t=
1mmbtu/hr = 27.49 m^3/hr = 20.62 kg/hr
NASDAQ

3.022	
0.109930884	mmbtu

UK historical average wholesale gas price

One **therm** is equal to about 105.5 me
Natural gas 2 year average = 39.24/Therm
Natural Gas 6 month average
Natural Gas 5 year average

Andrew NG Cost

0.035315 **MMBTU**		1 m3 to mm
$4		
	0.14126	USD/m3
	0.11	GBP/m3

UDS/GBP	1.27653

Fuel Gas Cost

Trains	1
Plant Operating	24
Days	365

Fuel Gas		Year 24	Year 25
		83%	94%
Fuel Gas	rated	151,220,937	171,232,470
Total Utilities		151,220,937	171,232,470

<img src='https://geo.yahoo.com/b?s=2114717799&t=
1mmbtu/hr = 27.49 m^3/hr = 20.62 kg/hr
NASDAQ

3.022
0.109930884 mmbtu

UK historical average wholesale gas price

One **therm** is equal to about 105.5 me
Natural gas 2 year average = 39.24/Therm
Natural Gas 6 month average
Natural Gas 5 year average

Andrew NG Cost

0.035315 **MMBTU** 1 m3 to mm
$4
0.14126 USD/m3
0.11 GBP/m3

UDS/GBP	1.27653

Disposals Costs

Disposal				Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13
		Unit	Total to dospose													
Waste Water	17,520	m3	8,855	17,520	17,520	17,520	17,520	17,520	17,520	17,520	17,520	17,520	17,520	17,520	17,520	17,520
Rubbish	0.1950	kg	32,916	6,419	6,419	6,419	6,419	6,419	6,419	6,419	6,419	6,419	6,419	6,419	6,419	6,419
Spent Amine	4,489	m3	4,489	14,065	14,065	14,065	14,065	14,065	14,065	14,065	14,065	14,065	14,065	14,065	14,065	14,065
Degraded Amine	2,995	m3	25,378	79,522	79,522	79,522	79,522	79,522	79,522	79,522	79,522	79,522	79,522	79,522	79,522	79,522
Molecular Sieve																
Sludge	674	T	67,650	67,650	67,650	67,650	67,650	67,650	67,650	67,650	67,650	67,650	67,650	67,650	67,650	67,650
Maintenance Disposals		nothing that will materially affect OPEX														
Total Disposals				185,176	185,176	185,176	185,176	185,176	185,176	185,176	185,176	185,176	185,176	185,176	185,176	185,176

CCGT	45794.3	45794.3	45794.3	45794.3	45794.3	45794.3	45794.3	45794.3	45794.3	45794.3	45794.3	45794.3	45794.3
CCC	139,382	139,382	139,382	139,382	139,382	139,382	139,382	139,382	139,382	139,382	139,382	139,382	139,382
	-	-	-	-	-	-	-	-	-	-	-	-	-

Disposals

Disposal	Year 14	Year 15	Year 16	Year 17	Year 18	Year 19	Year 20	Year 21	Year 22	Year 23	Year 24	Year 25
Waste Water	17,520	17,520	17,520	17,520	17,520	17,520	17,520	17,520	17,520	17,520	17,520	17,520
Rubbish	6,419	6,419	6,419	6,419	6,419	6,419	6,419	6,419	6,419	6,419	6,419	6,419
Spent Amine	14,065	14,065	14,065	14,065	14,065	14,065	14,065	14,065	14,065	14,065	14,065	14,065
Degraded Amine	79,522	79,522	79,522	79,522	79,522	79,522	79,522	79,522	79,522	79,522	79,522	79,522
Molecular Sieve												
Sludge	67,650	67,650	67,650	67,650	67,650	67,650	67,650	67,650	67,650	67,650	67,650	67,650
Maintenance Dis												
Total Disposals	185,176	185,176	185,176	185,176	185,176	185,176	185,176	185,176	185,176	185,176	185,176	185,176

CCGT	45794.3	45794.3	45794.3	45794.3	45794.3	45794.3	45794.3	45794.3	45794.3	45794.3	45794.3	45794.3
CCC	139,382	139,382	139,382	139,382	139,382	139,382	139,382	139,382	139,382	139,382	139,382	139,382
	-	-	-	-	-	-	-	-	-	-	-	-

Regulatory and Carbon Costs

		73%	84%	87%	95%	95%	84%	96%	96%	87%	96%	96%	85%
Regulatory Expenses	**Note**	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**	**Year 8**	**Year 9**	**Year 10**	**Year 11**	**Year 12**
1													
Sampling and Testing													
3rd Party inspection and testing	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000
Total Sampling and Testing		30000	30000	30000	30000	30000	30000	30000	30000	30000	30000	30000	30000

Climate Change Levy	18	3,642,447	3,999,861	4,083,625	4,340,923	4,349,043	3,983,397	4,365,284	4,373,405	4,081,355	4,378,277	4,381,525	4,007,759

Operating Conditions		24	hrs/day
Days/yr		365	
Trains		1	

Per Train	CO_2 Emission T/Hr												
100% Operation	25	2,890,620	3,324,375	3,426,030	3,738,285	3,748,140	3,304,395	3,767,850	3,777,705	3,423,276	3,783,618	3,787,560	3,333,960
Turndown	13												
Unabated (Start-Up, etc)	246	566,784	566,784	566,784	566,784	566,784	566,784	566,784	566,784	566,784	566,784	566,784	566,784
Shut-Down (Aux Boiler Running)	4.4	185,043	108,702	90,811	35,854	34,119	112,218	30,650	28,916	91,295	27,875	27,181	107,015

Start-ups	Hours unabated												
Projected Number of Cold Starts	20	3	3	3	3	3	3	3	3	3	3	3	3
Projected Number of Warm Starts	12	4	4	4	4	4	4	4	4	4	4	4	4
Projected Number of Hot starts	4	5	5	5	5	5	5	5	5	5	5	5	5

Regulatory and Carbon (

	96%	96%	88%	96%	96%	84%	96%	96%	88%	95%	95%	83%	94%
Regulatory Expenses	**Year 13**	**Year 14**	**Year 15**	**Year 16**	**Year 17**	**Year 18**	**Year 19**	**Year 20**	**Year 21**	**Year 22**	**Year 23**	**Year 24**	**Year 25**
1													
Sampling and Testing													
3rd Party inspection and testing	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000
Total Sampling and Testing	30000	30000	30000	30000	30000	30000	30000	30000	30000	30000	30000	30000	30000

Climate Change Levy	4,381,525	4,378,277	4,125,851	4,373,405	4,370,157	3,993,142	4,365,284	4,363,660	4,112,859	4,357,164	4,345,795	3,962,284	4,319,809

Operating Conditions
Days/yr
Trains

Per Train													
100% Operation	3,787,560	3,783,618	3,477,276	3,777,705	3,773,763	3,316,221	3,767,850	3,765,879	3,461,508	3,757,995	3,744,198	3,278,772	3,712,662
Turndown													
Unabated (Start-Up, etc)	566,784	566,784	566,784	566,784	566,784	566,784	566,784	566,784	566,784	566,784	566,784	566,784	566,784
Shut-Down (Aux Boiler Running)	27,181	27,875	81,791	28,916	29,610	110,137	30,650	30,997	84,567	32,385	34,813	116,728	40,363

Start-ups													
Projected Number of Cold Starts	3	3	3	3	3	3	3	3	3	3	3	3	3
Projected Number of Warm Starts	4	4	4	4	4	4	4	4	4	4	4	4	4
Projected Number of Hot starts	5	5	5	5	5	5	5	5	5	5	5	5	5

Subcontract Costs

Trains 1

Subcontracts	Note				Year 1	Year 2	Year 3	Year 4
ALL FIXED Costs								
O&M Contractor	Non-Routine Maintenance Modifications	1 year	10 days	£567,000	113400	113400	113400	113400
	Shutdowns and Turnarounds	6 years	57 days	£56,700,000				
Scaffolding			5 % of trade and maintenance hours		200,150	200,150	200,150	200,150
NDT	Ultrasonic, Radiographic, Dye Pen, Mag Particle			20m/5 yrs	800,000	800,000	800,000	800,000
Fixed Costs								
SERVI CES								
Security		Continuous	Continuous	362,192	191,535	191,535	191,535	191,535
Cleaning	Daily Cleaining of non-PPE facilities (Office, Lockers, training area,	Evening - 5 days per week	Continuous - cost per year	258,989	136,959	136,959	136,959	136,959
IT	IT Service Desk, Maintain, and Support.	Weekdays		729,479	385,765	385,765	385,765	385,765
Logistics			14 days/year	5,880	5,880	5,880	5,880	5,880
Side Scan Sonar	Route survey of Subsea Pipelines	5 years - cost per platform	228000	228,000				
ROV	Subsurface Inspection and Maintenance		135352	135,352	135,352	135,352	135,352	135,352
Training	Offshore Survival (All Ops and Maint Technical Staff)	Tech Staff: 14 HSE Courses pre-operation + refreshers.	Mix	Training = £169/day -person (assume in house delivery as	187,210	187,210	187,210	187,210
SUPPLY / HIRE								
Walk to Work Vessel	Supply walk to work vessel to take O&M team out to platform. Assume:	1 platform every other monh	14 Days - 4750 day rate	399000	399,000	399,000	399,000	399,000
Supply Boat	To support Walk to Work Vessel See above	See above	22400 per trip, every other mont	134400	134,400	134,400	134,400	134,400
Total Fixed								
Total Subcontracts					2,689,651	2,689,651	2,689,651	2,689,651

Subcontract Costs

Trains

Subcontracts	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
ALL FIXED Costs											
O&M Contractor	113400	113400	113400	113400	113400	113400	113400	113400	113400	113400	113400
		11,340,000						11,340,000			
Scaffolding	200,150	200,150	200,150	200,150	200,150	200,150	200,150	200,150	200,150	200,150	200,150
NDT	800,000	800,000	800,000	800,000	800,000	800,000	800,000	800,000	800,000	800,000	800,000
Fixed Costs											
SERVI CES											
Security	191,535	191,535	191,535	191,535	191,535	191,535	191,535	191,535	191,535	191,535	191,535
Cleaning	136,959	136,959	136,959	136,959	136,959	136,959	136,959	136,959	136,959	136,959	136,959
IT	385,765	385,765	385,765	385,765	385,765	385,765	385,765	385,765	385,765	385,765	385,765
Logistics	5,880	5,880	5,880	5,880	5,880	5,880	5,880	5,880	5,880	5,880	5,880
Side Scan Sonar	£228,000					£228,000					£228,000
ROV	135,352	135,352	135,352	135,352	135,352	135,352	135,352	135,352	135,352	135,352	135,352
Training	187,210	187,210	187,210	187,210	187,210	187,210	187,210	187,210	187,210	187,210	187,210
SUPPLY / HIRE											
Walk to Work Vessel	399,000	399,000	399,000	399,000	399,000	399,000	399,000	399,000	399,000	399,000	399,000
Supply Boat	134,400	134,400	134,400	134,400	134,400	134,400	134,400	134,400	134,400	134,400	134,400
Total Fixed											
Total Subcontracts	2,917,651	14,029,651	2,689,651	2,689,651	2,689,651	2,917,651	2,689,651	14,029,651	2,689,651	2,689,651	2,917,651

Subcontract Costs

Trains

Subcontracts	Year 16	Year 17	Year 18	Year 19	Year 20	Year 21	Year 22	Year 23	Year 24	Year 25
ALL FIXED Costs										
O&M Contractor	113400	113400	113400	113400	113400	113400	113400	113400	113400	113400
			11,340,000						11,340,000	
Scaffolding	200,150	200,150	200,150	200,150	200,150	200,150	200,150	200,150	200,150	200,150
NDT	800,000	800,000	800,000	800,000	800,000	800,000	800,000	800,000	800,000	800,000
Fixed Costs										
SERVI CES										
Security	191,535	191,535	191,535	191,535	191,535	191,535	191,535	191,535	191,535	191,535
Cleaning	136,959	136,959	136,959	136,959	136,959	136,959	136,959	136,959	136,959	136,959
IT	385,765	385,765	385,765	385,765	385,765	385,765	385,765	385,765	385,765	385,765
Logistics	5,880	5,880	5,880	5,880	5,880	5,880	5,880	5,880	5,880	5,880
Side Scan Sonar					£228,000					£228,000
ROV	135,352	135,352	135,352	135,352	135,352	135,352	135,352	135,352	135,352	135,352
Training	187,210	187,210	187,210	187,210	187,210	187,210	187,210	187,210	187,210	187,210
SUPPLY / HIRE										
Walk to Work Vessel	399,000	399,000	399,000	399,000	399,000	399,000	399,000	399,000	399,000	399,000
Supply Boat	134,400	134,400	134,400	134,400	134,400	134,400	134,400	134,400	134,400	134,400
Total Fixed										
Total Subcontracts	2,689,651	2,689,651	14,029,651	2,689,651	2,917,651	2,689,651	2,689,651	2,689,651	14,029,651	2,917,651

Adminsitrative and Other Costs

Trains	1

Other Expenses	Note	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9
Administrative Expenses										
Administration	4.4/hr per person	928,400	928,400	928,400	928,400	928,400	928,400	928,400	928,400	928,400
Insurance	2.4% capex (Teesside OPEX)	42,279,839	42,279,839	42,279,839	42,279,839	42,279,839	42,279,839	42,279,839	42,279,839	42,279,839
Financial Security for CO2 Storage	5.679m for 10MTPA	1,135,800	1,135,800	1,135,800	1,135,800	1,135,800	1,135,800	1,135,800	1,135,800	1,135,800
Office furniture and equipment, hardware	£800/person every 4 years	21,100	21,100	21,100	21,100	21,100	21,100	21,100	21,100	21,100
PPE	Previous proposal estimate	168,800	168,800	168,800	168,800	168,800	168,800	168,800	168,800	168,800
HVAC	Annual contract scaled	27,910	27,910	27,910	27,910	27,910	27,910	27,910	27,910	27,910
Generation/operating licenses	negl.									
Transmission Fees	£7/kw - National Grid rates	4,430,064	4,430,064	4,430,064	4,430,064	4,430,064	4,430,064	4,430,064	4,430,064	4,430,064
Local Taxes	business rates scaled by plant size	1,911,159	1,911,159	1,911,159	1,911,159	1,911,159	1,911,159	1,911,159	1,911,159	1,911,159
Technology licences	Previous project cost	10,732,050								
Auditing	.06% Gross Revenue	215,409.00	247,732.43	300,942.48	278,577.00	279,311.39	246,243.52	280,780.18	281,514.58	255,102.53
Legal Counsel	Salary cost from SNC Data	395,000	395,000	395,000	395,000	395,000	395,000	395,000	395,000	395,000
General small tools and consumables	Hourly cost - based on multiple project history	262,080	262,080	262,080	262,080	262,080	262,080	262,080	262,080	262,080
Total Other Expenses		62,245,531	51,545,805	51,599,015	51,576,649	51,577,383	51,544,316	51,578,852	51,579,587	51,553,175
			9%	2.2%	82.0%					
Scale based on staffing. Year 1, add licenses to CCC										
CCGT		21,400,774	21,897,000	21,919,604	21,910,103	21,910,415	21,896,368	21,911,039	21,911,351	21,900,131
CCC		32,132,824	21,897,000	21,919,604	21,910,103	21,910,415	21,896,368	21,911,039	21,911,351	21,900,131
Pipelines		2,012,385	2,059,047	2,061,173	2,060,279	2,060,309	2,058,988	2,060,367	2,060,397	2,059,342
Offshore		6,699,548	5,692,757	5,698,633	5,696,163	5,696,244	5,692,592	5,696,407	5,696,488	5,693,571

Adminsitrative and Other Costs

Trains	1

Other Expenses	Note	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15	Year 16	Year 17	Year 18
Administrative Expenses										
Administration	4.4/hr per person	928,400	928,400	928,400	928,400	928,400	928,400	928,400	928,400	928,400
Insurance	2.4% capex (Teesside OPEX)	42,279,839	42,279,839	42,279,839	42,279,839	42,279,839	42,279,839	42,279,839	42,279,839	42,279,839
Financial Security for CO2 Storage	5.679m for 10MTPA	1,135,800	1,135,800	1,135,800	1,135,800	1,135,800	1,135,800	1,135,800	1,135,800	1,135,800
Office furniture and equipment, hardware	£800/person every 4 years	21,100	21,100	21,100	21,100	21,100	21,100	21,100	21,100	21,100
PPE	Previous proposal estimate	168,800	168,800	168,800	168,800	168,800	168,800	168,800	168,800	168,800
HVAC	Annual contract scaled	27,910	27,910	27,910	27,910	27,910	27,910	27,910	27,910	27,910
Generation/operating licenses	negl.									
Transmission Fees	£7/kw - National Grid rates	4,430,064	4,430,064	4,430,064	4,430,064	4,430,064	4,430,064	4,430,064	4,430,064	4,430,064
Local Taxes	business rates scaled by plant size	1,911,159	1,911,159	1,911,159	1,911,159	1,911,159	1,911,159	1,911,159	1,911,159	1,911,159
Technology licences	Previous project cost									
Auditing	.06% Gross Revenue	281,955.21	282,248.97	248,446.70	282,248.97	281,955.21	259,126.61	281,514.58	281,220.82	247,124.79
Legal Counsel	Salary cost from SNC Data	395,000	395,000	395,000	395,000	395,000	395,000	395,000	395,000	395,000
General small tools and consumables	Hourly cost - based on multiple project history	262,080	262,080	262,080	262,080	262,080	262,080	262,080	262,080	262,080
Total Other Expenses		51,580,027	51,580,321	51,546,519	51,580,321	51,580,027	51,557,199	51,579,587	51,579,293	51,545,197

Scale based on staffing. Year 1, add licenses to CCC										
CCGT		21,911,538	21,911,663	21,897,304	21,911,663	21,911,538	21,901,841	21,911,351	21,911,226	21,896,742
CCC		21,911,538	21,911,663	21,897,304	21,911,663	21,911,538	21,901,841	21,911,351	21,911,226	21,896,742
Pipelines		2,060,414	2,060,426	2,059,076	2,060,426	2,060,414	2,059,502	2,060,397	2,060,385	2,059,023
Offshore		5,696,536	5,696,569	5,692,836	5,696,569	5,696,536	5,694,015	5,696,488	5,696,455	5,692,690

Adminsitrative and Other Costs

Trains	1

Other Expenses	Note	Year 19	Year 20	Year 21	Year 22	Year 23	Year 24	Year 25
Administrative Expenses								
Administration	4.4/hr per person	928,400	928,400	928,400	928,400	928,400	928,400	928,400
Insurance	2.4% capex (Teesside OPEX)	42,279,839	42,279,839	42,279,839	42,279,839	42,279,839	42,279,839	42,279,839
Financial Security for CO2 Storage	5.679m for 10MTPA	1,135,800	1,135,800	1,135,800	1,135,800	1,135,800	1,135,800	1,135,800
Office furniture and equipment, hardware	£800/person every 4 years	21,100	21,100	21,100	21,100	21,100	21,100	21,100
PPE	Previous proposal estimate	168,800	168,800	168,800	168,800	168,800	168,800	168,800
HVAC	Annual contract scaled	27,910	27,910	27,910	27,910	27,910	27,910	27,910
Generation/operating licenses	negl.							
Transmission Fees	£7/kw - National Grid rates	4,430,064	4,430,064	4,430,064	4,430,064	4,430,064	4,430,064	4,430,064
Local Taxes	business rates scaled by plant size	1,911,159	1,911,159	1,911,159	1,911,159	1,911,159	1,911,159	1,911,159
Technology licences	Previous project cost							
Auditing	.06% Gross Revenue	280,780.18	280,633.30	257,951.58	280,045.79	279,017.63	244,334.09	276,667.57
Legal Counsel	Salary cost from SNC Data	395,000	395,000	395,000	395,000	395,000	395,000	395,000
General small tools and consumables	Hourly cost - based on multiple project history	262,080	262,080	262,080	262,080	262,080	262,080	262,080
Total Other Expenses		51,578,852	51,578,705	51,556,024	51,578,118	51,577,090	51,542,406	51,574,740

Scale based on staffing. Year 1, add licenses to CCC							
CCGT	21,911,039	21,910,977	21,901,341	21,910,727	21,910,290	21,895,557	21,909,292
CCC	21,911,039	21,910,977	21,901,341	21,910,727	21,910,290	21,895,557	21,909,292
Pipelines	2,060,367	2,060,361	2,059,455	2,060,338	2,060,297	2,058,911	2,060,203
Offshore	5,696,407	5,696,390	5,693,885	5,696,325	5,696,212	5,692,381	5,695,952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Building
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